MSC INTERNAL NOTE NO. 69-FM-202

PROJECT APOLLO

OPERATIONAL SPACECRAFT ATTITUDE SEQUENCE FOR APOLLO 11

By Mission Design Section
TRW Systems Group

July 8, 1969

MISSION PLANNING AND ANALYSIS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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Memorandum

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NASA - Manned Spacecraft Center
Mission Planning & Analysis Division

TO : See attached list

DATE: JUL 7 1969

File No. 69-FM13-383

FROM : FM13/Chief, Mission Planning Support Office

SUBJECT: Apollo 11 Attitude Timeline

The attached document presents the Apollo 11 CSM and LM attitude sequences for cislunar and lunar orbit operations. The attitude sequence is based on the Revised Operational Trajectory, 69-FM-186, and completely replaces the Preliminary Attitude Sequence document, 69-FM-103.

In the text of this document, it is stated that after undocking the LM nulls the relative rates and that following LM inspection, the LM performs active stationkeeping. In order to least perturb the LM state vector, the LM will now null only the ΔV imparted to the LM by undocking, and then the CSM will do the active stationkeeping.

The tables in this document contain local horizontal and IMU gimbal angles for the CSM and LM. A supplementary table is attached to this cover memorandum which provides the LM FDAI angles for each LM attitude.

The LM jettison attitude is being changed to provide LM communications.

Page changes to this document will be issued as they are available.

for R. P. Parten

APPROVED BY:

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Enclosure

Addressees:
(See attached list)
(Distribution "A")

FM13:JRGurley:lg

LM F.D.A.I. ANGLES FOR MISSION G

TIME	P	Y	R
100:15:00	193.8	60.0	0
100:17:19	303.8	0	0
100:18:40	123.8	-18.0	180.0
100:20:19	303.8	0	0
100:39:50	303.8	0	0
100:40:05	303.8	0	0
100:45:10	283.6	0	0
100:54:28	278.5	0	0
100:54:30	278.5	0	0
101:00:00	272.6	0	0
101:30:27	272.6	0	0
101:30:30	272.6	0	0
101:34:00	294.9	0	0
101:35:21	294.9	0	0
101:38:48	294.9	0	0
101:39:16	296.3	0	0
101:40:42	296.3	0	0
101:40:46	296.3	0	0
101:40:48	195.7	0	0
101:43:48	197.6	0	0
101:45:48	198.7	0	0
101:53:48	106.5	0	0
101:58:48	286.5	0	180.0
102:16:30	286.5	0	180.0
102:18:30	286.5	0	180.0

LM F.D.A.I. ANGLES FOR MISSION G
(continued)

TIME	P	Y	R
102:18:35	286.5	0	180.0
102:31:14	286.5	0	180.0
102:35:14	286.5	0	180.0
102:36:14	279.8	0	180.0
102:38:14	86.6	0	0
102:47:11	0	0	0
124:23:21	0	0	0
124:30:44	257.4	0	0
124:35:44	333.3	0	0
124:36:49	333.3	0	0
124:40:44	333.3	0	0
124:55:44	272.7	0	0
125:10:06	223.4	0	0
125:11:19	221.5	0	0
125:21:19	187.8	0	0
125:22:04	179.0	0	0
125:25:50	170.0	0	0
125:28:04	80.5	0	0
125:57:41	352.8	0	0
126:07:37	352.8	0	0
126:19:37	352.8	0	0
126:19:39	5.3	0	0
126:23:39	331.3	0	0
126:34:42	312.3	0	0
126:42:39	273.5	0	0

LM F.D.A.I. ANGLES FOR MISSION G
(continued)

TIME	P	Y	R
126:58:08	274.6	-.2	.1
126:58:30	261.2	0	0
127:05:58	239.4	0	0
127:21:18	239.9	0	0
127:39:24	240.1	0	0
127:39:35	243.3	.3	.4
127:40:37	243.5	.3	.4
127:40:46	243.2	.3	.4
127:42:16	243.4	.3	.4
127:42:20	243.7	.3	.3
127:43:35	244.0	.3	.3
127:43:39	152.0	0	0
127:47:00	152.0	0	0
127:52:44	152.0	0	0
128:00:00	152.0	0	0

TABLES

FIGURES

FIGURES

FIGURES

OPERATIONAL SPACECRAFT ATTITUDE SEQUENCE FOR MISSION G

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1. SUMMARY AND INTRODUCTION

1.1 General

This document contains the operational spacecraft attitude sequence for mission G. The purpose of the document is to provide a source of spacecraft (command and service module (CSM) and lunar module (LM)) attitude data for the nominal cislunar and lunar orbit mission operations. Changes and revisions to the preliminary G mission lunar orbit attitude sequence, Reference 1, have been incorporated in order to present the latest possible mission planning inputs. These updates include several changes to the attitude philosophy. The lunar orbit sleep attitude has been changed to compensate for reaction control subsystem (RCS) overheating. The landmark used in the first tracking event has been changed to coincide with the landmark used during descent. The docked CSM/LM roll of 180-degrees before undocking to shade the spacecraft windows and the subsequent 180-degree roll for communications prior to separation have been eliminated. The time of descent orbit insertion (DOI) has slipped one revolution to provide Goldstone deep-dish tracking. The LM procedure from DOI to landing have been updated. A strip photography and crew optical alignment sight (COAS) tracking period now interrupts the CSM sleep period while the LM is on the surface. A CSM inertial measurement unit (IMU) alignment has been added during rendezvous. The LM burn attitudes during rendezvous are no longer held inertially fixed. The 180-degree roll in preparation for docking has been eliminated. A revolution in lunar orbit after CSM/LM docking has been added. The LM jettison procedures have been changed. In addition, the cislunar attitude sequence has been included.

Cislunar and lunar orbit data for the spacecraft operational attitude sequence are presented in the following format:

1. Discussion of the major attitude events occurring in the mission

2. Figures illustrating the spacecraft attitude events and activities

3. An attitude timeline listing the chronological sequence of events (Table I). Mission event times were obtained from the Apollo 11 Final Flight Plan, Reference 2.

4. Tabular data summarizing the pertinent spacecraft attitude and orbital parameters (Table II)

The pertinent spacecraft attitude and orbital data presented include

1. Mission time

2. Event

3. Selenographic position

4. Local horizontal attitude; that is, the local horizontal X-axis lies along the local horizontal in the direction of motion, the Z-axis lies along the negative radius vector and Y-axis completes the right hand, orthogonal system. Figure 1 presents a method for converting a local horizontal pitch orientation into a landing site inertial pitch orientation for lunar landing site 2.

5. Inertial measurement unit (IMU) gimbal angles are presented for the CSM during CSM/LM docked and CSM solo operations and for both the CSM and LM during two-vehicle operations. Flight director attitude indicator (FDAI) readings are not presented. The exact conversion from IMU to FDAI inertial angles for the LM can be found in Reference 3. The conversion is necessary because the pilot orientations differ between the CSM and LM even though the guidance and navigation (G&N) orientations coincide.

6. Spacecraft look angles (theta, phi), as defined in Figure 2, to the earth, moon, sun, and other vehicle are presented where applicable.

1.2 Trajectory Profile

The CSM and LM state vector and ephemeris data for generating the CSM solo and the docked CSM/LM attitude data were obtained from the Lunar Mission Analysis Branch of MPAD-MSC. The LM descent and ascent trajectory parameters were furnished by the Landing Analysis Branch of MPAD-MSC, while the lunar orbit rendezvous trajectory parameters were furnished by the Orbital Mission Analysis Branch of MPAD-MSC. The complete lunar orbit phase of the mission was precision integrated on the Apollo Reference Mission Program, Version ARM07.

Launch date for the mission is July 16, 1969, at 9:31:45.3 a.m., eastern daylight time, with a 72-degree launch azimuth and a Pacific translunar injection (TLI) on the first opportunity.

Translunar and transearth flight times are approximately 73 hours and 59 hours, respectively. The lunar orbit phase consists of 30 revolutions (approximately 59 hours) in lunar orbit including a LM lunar stay time of approximately 22 hours.

1.3 Attitude Data Generation

For the CSM/LM docked and the CSM solo operations, the Apollo Mission Attitude Requirements (AMAR) Program was used to produce the attitude data required to define the nominal mission attitude timeline. For the two-vehicle (CSM and LM active operations) portion of the mission, the ARM07 Program was used to produce the attitude data. For the purpose of data generation, instantaneous maneuvers were assumed in reorienting the spacecraft from an existing attitude. Appropriate time intervals are provided for finite reorientations in the timeline. The maneuver times are representative only, and they are not intended to reflect actual rates.

Spacecraft attitude data will be supplied to the Flight Planning Branch of FCSD-MSC for inclusion in the Apollo 11 flight plan. In addition, computer tapes of the mission trajectory and attitude profile are available. Request for these tapes should be made through the Mission Planning Support Office of MPAD-MSC.

1.4 Spacecraft Attitude Constraints

The CSM and LM, both in the docked and undocked configurations, are subject to attitude restrictions throughout the mission. In general, these restrictions are imposed by subsystem requirements, mission requirements, or geometry limitations.

The major constraints considered in defining the G mission spacecraft attitude timeline are enumerated below. Unless noted otherwise, the constraints are relevant to specific events or operations. Violation of any constraint is noted in the attitude timeline discussion (Sections 3, 4, 5, and 6).

1. Earth Orbit and Cislunar Phases

a. The S-IVB/SLA/CSM/LM configuration in earth orbit coast should maintain a local horizontal attitude hold with the CSM plus X-axis forward along the direction of motion and the crew heads down (CSM minus Z-axis towards the earth). This local attitude hold should be established following parking orbit insertion and maintained until just prior to the translunar injection burn.

b. CSM tracking, telemetry, and voice are required during transposition, docking, and ejection.

c. CSM tracking, command, telemetry, and voice are required for 1 hour following ejection.

d. CSM IMU gimbal lock must be avoided for all events and operations in the cislunar phase. For the G mission, IMU gimbal lock is assumed to occur when the angle between the outer and inner gimbal axes is less than 45 degrees.

e. During docking with no artificial lighting, the sun must lie between 90 and 150 degrees of the CSM positive X-axis.

f. Pitch and roll maneuvers required for transposition and docking are performed at 5 degrees per second.

g. CSM monitoring of the S-IVB is required for 1 hour following ejection.

h. During passive thermal control (PTC) the angle between the line of sight to the sun and the CSM Y-Z plane must be less than 30 degrees. A roll rate between one and three revolutions per hour must also be maintained.

2. Lunar Orbit Phase

a. CSM and LM gimbal lock must be avoided for all events and operations in the lunar orbit phase. For the G mission, IMU gimbal lock is assumed to occur when the angle between the outer and inner gimbal axes is less than 45 degrees.

b. CSM and LM high-gain communications are highly desirable when earth line of sight exists and the attitude does not conflict with other mission objectives.

c. During the sleep period prior to LM undocking, the CSM/LM docked attitude must provide MSFN coverage through the CSM S-band steerable antenna when earth line of sight exists. A nominal thermal environment must also be provided for the CSM RCS quads by orienting the spacecraft with respect to the sun.

d. CSM and LM IMU alignments in lunar orbit must avoid sunlight interference. For the G mission, this is accomplished by scheduling these events to occur in darkness. During the alignment operation, the spacecraft attitude must provide the sextant (SXT) field of coverage with at least two reference stars from 20 to 90 degrees apart. The shaft drive axis (SDA) must be at least 20 degrees above the lunar horizon.

e. During undocked activities, CSM and LM attitudes should be favorable for VHF communications unless precluded by other requirements.

f. During CSM landmark tracking, the actual marking operation should be confined to the portion of the orbit above 35 degrees elevation angle with respect to the landmark. The CSM attitude and attitude rate should be established to allow maximum optics coverage during this time. Due to an optics system constraint, the CSM attitude rate while marking is limited to a rate less than 0.5 degree per second.

g. LM inspection by the CSM must be made in sunlight as soon as possible after undocking.

h. Tracking periods during undocked activities specify a line of sight be maintained between the vehicles which satisfies the respective tracking requirements of each. The initial tracking attitude for the CSM and LM should be heads down and heads up, respectively, except prior to PDI.

i. For the CSM-LM docking maneuver performed in sunlight, the angle between the minus X-axis of the active vehicle and the sun should not be greater than 90 degrees to avoid glare interference to the active vehicle.

j. During terminal rendezvous and docking, at ranges greater than 50 feet the LM attitude must provide CSM visibility through the LM forward (plus Z) windows. After pitchover to the docking orientation at a range of 50 feet, CSM visibility is required through the overhead (plus X) window.

Further detail on lunar mission attitude constraints may be obtained from Reference 4. Information concerning CSM/LM docked high-gain communications is found in Reference 5.

2. SYMBOLS

AGS	abort guidance system
AMAR	Apollo Mission Attitude Requirements Program
AOT	alignment optical telescope
APS	ascent propulsion subsystem
ARM07	Apollo Reference Mission Program, Version ARM07
CDH	constant delta altitude
CM	command module
CMP	command module pilot
COAS	crew optical alignment sight
CP	control point
CPA	closest point of approach
CSI	coelliptic sequence initiation
CSM	command and service module
DOI	descent orbit insertion
DPS	descent propulsion subsystem
FCSD-MSC	Flight Crew Support Division - Manned Spacecraft Center
FDAI	flight director attitude indicator
g. e. t.	ground elapsed time (hr:min:sec)
G&N	guidance and navigation
HGA	high-gain antenna
IGA	inner gimbal angle
IMU	inertial measurement unit

SYMBOLS (Continued)

LM	lunar module
LOI-1	first lunar orbit insertion burn
LOI-2	lunar orbit circularization burn
LR	landing radar
LS	landing site
MCC	midcourse correction
MGA	middle gimbal angle
MPAD-MSC	Mission Planning and Analysis Division - Manned Spacecraft Center
MI	mirror image
MSFN	Manned Space Flight Network
OGA	outer gimbal angle
PDI	powered descent initiation
PTC	passive thermal control
RCS	reaction control subsystem
REFSMMAT	reference to stable member coordinate transformation matrix
RR	rendezvous radar
SCT	scanning telescope
SDA	shaft drive axis
SLA	spacecraft LM adapter
SM	service module
SPS	service propulsion system
SXT	sextant
S-IVB	third stage of Saturn V vehicle

SYMBOLS (Continued)

TEI	transearth injection
TLI	translunar injection
TPF	terminal phase final
TPI	terminal phase initiation
VHF	very high frequency
ΔV	velocity increment

3. EARTH ORBIT

The S-IVB/SLA/LM/CSM configuration is inserted into 100-nautical mile altitude circular parking orbit by the Saturn V booster at 00:11:24 g. e. t. The booster/spacecraft attitude at insertion burn termination is inertially fixed for 20 seconds. Following this hold, the S-IVB attitude control system positions the S-IVB (and CSM) X-axis along the local horizontal in the direction of motion. The CSM plus Z-axis is directed along the current position vector. This alignment (which is heads down for the crew) is maintained by an S-IVB orbital pitch rate during the earth orbit phase of the mission. This attitude provides communication coverage during passes over manned space flight network (MSFN) stations. The local attitude hold is terminated prior to ignition of the TLI burn which occurs at 02:41:39 g. e. t. during the second earth parking orbit revolution. Attitude control for the burn is also through the S-IVB control system.

Spacecraft position and attitude data for the earth orbit phase of the mission are listed in Table II(a). The IMU gimbal angle data for this phase apply to the launch pad alignment of the spacecraft IMU. The transformation matrices (REFSMMAT) for this and other nominal IMU alignments pertaining to various mission phases are given in Table III. Alignment of the IMU to a new inertial reference is noted in both the discussion and the tabular IMU gimbal angle data.

4. TRANSLUNAR ATTITUDE PROFILE

Presented in this section are major translunar events for which specific attitude sequences have been determined. These events include the transposition, docking, ejection sequence, the spacecraft evasive maneuver, and the PTC periods. Table II(b) lists the spacecraft attitude data for the translunar coast phase which begins at TLI burn termination (02:49:46 g. e. t.) and ends at lunar orbit insertion (LOI-1) burn ignition (75:54:28 g. e. t.). Preflight attitudes for IMU alignments, midcourse corrections, and cislunar navigation cannot be predicted precisely; attitude data for these events are, therefore, not available. The nominal mission event times are indicated, however, as obtained from Reference 2. Figure 3 is a schematic representation of the major cislunar events.

4. 1 Post-TLI Sequence of Events

Termination of the TLI burn occurs at 02:49:46 g. e. t. The S-IVB attitude control system maintains the burnout attitude inertially fixed for 20 seconds following thrust termination. A local horizontal attitude hold is then established by the S-IVB with the CSM plus X-axis forward in the direction of motion and the CSM plus Z-axis up along the local vertical. At TLI cutoff plus 15 minutes, the S-IVB orients the spacecraft/booster configuration to the required inertial attitude for transposition and docking. This attitude, in terms of the local horizontal orientation at TLI cutoff plus 15 minutes, consists of a positive 120-degree pitch, a positive 40-degree yaw, and a roll of 180 degrees for the S-IVB. The CSM orientation is identical except for the roll orientation which is 0 degree for the CSM. With this orientation, the S-IVB and CSM are prepared for the transposition and docking maneuver sequence initiated at TLI cutoff plus 25 minutes with CSM/S-IVB separation. A CSM RCS plus X-axis translation burn of. 8 foot per second provides the CSM-S-IVB separation rate. Approximately 2 minutes later, (TLI cutoff plus 27 minutes), the CSM nulls the separation rate and pitches 180 degrees to prepare for the CSM/LM docking maneuver. After aligning to the proper CSM/LM docking index (LM plus Z-axis in the CSM minus Z-plus Y quadrant 60 degrees (± 10 degrees) from the CSM minus Z-axis), the CSM closes with the LM (and S-IVB) and completes the docking maneuver. LM ejection is accomplished at approximately TLI plus 80 minutes after which the CSM orients to the S-IVB evasive maneuver attitude. The evasive maneuver burn by the CSM service propulsion system (SPS) is scheduled to occur at TLI cutoff plus 110 minutes. The spacecraft attitude for this maneuver is designed to account for the required SPS thrusting direction, allow the command module pilot (CMP) in the left-hand seat to view the S-IVB through the side window, and also provide CSM high-gain antenna (HGA) communications. With these considerations, the CSM local horizontal attitude for the burn is pitched 75 degrees below the local horizontal in the direction of motion and rolled positively 56 degrees.

The CSM IMU realignment and cislunar navigation sightings are performed beginning at 05:30:00 g. e. t. The navigation sightings consists of five sets of star-earth horizon sightings.

The first midcourse burn is scheduled at 11:45:00 g. e. t. The primary purpose of this burn is to reduce the trajectory dispersions.

This maneuver completes the post-TLI activities. Information for this mission phase was obtained from the G mission flight plan, Reference 2.

4. 2 Passive Thermal Control

The translunar coast period following the post-TLI events and ending at the time for the last translunar midcourse correction consists, in terms of spacecraft attitude, primarily of maintaining an acceptable thermal environment for the various spacecraft subsystems. This nominal thermal environment is provided by the PTC mode which involves spinning the spacecraft about the body X-axis at approximately one revolution every 20 minutes. The spacecraft is aligned initially so that the X-axis is normal (within ±30 degrees) to the sun, thereby equalizing the solar heat incidence when the spin is induced. Once the spin rate is established, all RCS control jets may be disabled (true PTC), or the pitch-yaw control may be maintained in wide deadband which is planned for mission G. Simulation of PTC periods for this document assumed exact attitude control in all channels (pitch, yaw, and roll). The REFSMMAT used in establishing the spacecraft PTC orientation is defined in Table III. The IMU Y-axis pointing was determined so that the possibility of gimbal lock occurring for transearth midcourse burns is minimized. The PTC attitude is also designed to optimize spacecraft-MSFN communications by orienting the spacecraft X-axis as near normal to the earth line of sight as possible while satisfying the other attitude constraints noted previously.

4. 3 Pre-LOI Events

The pre-LOI sequence of events is assumed to begin at approximately 70:00:00 g. e. t. when the CSM IMU is aligned to the landing site REFSMMAT. This inertial IMU alignment corresponds to a local horizontal attitude of 90. 0, 0. 0, 0. 0 degrees (pitch, yaw, roll) with the nominal (assumed) time of LM touchdown and descent orbit approach azimuth. The IMU realignment is followed at approximately 70:55:00 g. e. t. by a midcourse correction, if required. Another IMU realignment occurs at 73:32:00 g. e. t.

The spacecraft maneuvers to the LOI-1 burn attitude at 74:05:00 g. e. t. The spacecraft is rolled 60 degrees for MSFN 5 minutes later. This attitude is terminated after 5 minutes with a -60 degree roll to the LOI-1 burn attitude. At 74:25:00 g. e. t., the spacecraft begins a -0. 2 degree per second pitch rate for lunar surface observation. After pitching 360 degrees, the attitude is held inertially fixed through the LOI-1 burn.

5. LUNAR ORBIT ATTITUDE PROFILE

This section contains a detailed description of the lunar orbit attitude profile. The events are discussed in chronological order with only those mission events which affect the attitude profile being mentioned.

The mission G lunar orbit profile may be divided into five major sections:

1. First lunar orbit insertion burn (LOI-1) cutoff to CSM/LM undocking

2. CSM/LM undocking to LM landing

3. LM landing to LM lift-off (CSM solo operations)

4. LM lift-off to CSM/LM docking

5. CSM/LM docking to TEI burn ignition.

The discussion will be divided into these sections with the first, third, and fifth sections being discussed revolution by revolution, while the second and fourth sections are discussed according to major events. For the purpose of this document, a vehicle revolution will be referenced to the lunar surface. The first vehicle revolution is assumed to start at LOI-1 burn cutoff and end at 180 degrees selenographic longitude. All other revolutions start and end at 180 degrees selenographic longitude except the thirty-first revolution which ends at transearth injection (TEI) burn ignition.

An attitude timeline listing the chronological sequence of events during the lunar orbit is presented in Table I(b). Detailed trajectory and attitude data for the lunar orbit are presented in Table II(c).

5.1 LOI-1 Burn Cutoff to CSM/LM Undocking

Detailed trajectory and attitude data for the LOI-1 burn cutoff to CSM/LM undocking portion of the lunar orbit are presented in Table II(c), part 1.

5.1.1 First revolution (Figure 4). - The LOI-1 burn is designed to insert the CSM/LM into a 60- by 170-nautical mile elliptical parking orbit around the moon. The burn is performed by the CSM SPS engine. The CSM/LM is in a retrograde attitude, and the crew is heads down to afford visual reference with the lunar surface. The CSM/LM is held inertially fixed until the vehicle is maneuvered to the lunar observation attitude. The CSM attitude, with respect to the local horizontal orientation, is a pitch of -45 degrees and a roll of 180 degrees. This lunar observation

attitude allows observation of the CSM/LM groundtrack through the CSM hatch window and oblique views of the lunar surface through the CSM side windows. This attitude is held locally fixed through completion of the first revolution. The CSM S-band HGA communications will be available from acquisition of MSFN line of sight to loss of MSFN line of sight.

5.1.2 Second revolution (Figure 5). - At the beginning of the second revolution, the spacecraft is in the locally fixed lunar observation attitude. This attitude is held locally fixed until the CSM/LM enters darkness. At this time, the local attitude hold is terminated, and the vehicle attitude is maintained inertially fixed to allow for a CSM IMU realignment. The IMU realignment to the landing site REFSMMAT occurs approximately 3 minutes after the CSM/LM enters darkness. Approximately 17 minutes prior to loss of MSFN line of sight, the CSM/LM is maneuvered to LOI-2 burn attitude. This attitude is held inertially fixed until just prior to the completion of the second revolution when the LOI-2 burn is performed. This circularization burn transforms the initial elliptical parking orbit into a 60-nautical mile circular orbit. The SPS burn is performed with the CSM/LM in a retrograde attitude, and the crew is heads down to afford visual reference with the lunar surface. The LOI-2 burn cutoff attitude is maintained inertially fixed through completion of the second revolution. The CSM S-band HGA communications will be available from acquisition of MSFN line of sight until the maneuver to the LOI-2 burn attitude.

5.1.3 Third revolution (Figure 6). - At the beginning of the third revolution, the spacecraft is in the inertially fixed LOI-2 burn cutoff attitude and is maintained inertially fixed until the CSM/LM is maneuvered to the lunar observation attitude. The lunar observation attitude is held locally fixed until the CSM/LM enters darkness. At this time, the local attitude hold is terminated and the vehicle attitude is maintained inertially fixed to allow for a CSM IMU realignment. The IMU realignment to the landing site REFSMMAT occurs immediately after the CSM/LM enters darkness. This attitude is held inertially fixed through the completion of the third revolution. The CSM S-band HGA communications will be available from acquisition of MSFN line of sight to loss of MSFN line of sight.

5.1.4 Fourth revolution (Figure 7). - At the beginning of the fourth revolution, the spacecraft is in an inertially fixed S-band HGA communications attitude. This attitude is held inertial until approximately 7 minutes prior to acquisition of MSFN line of sight. The CSM/LM is then maneuvered to the mode I landmark tracking attitude. As explained in Section 5.1.5, the mode I attitude is such that the spacecraft when inertially held will be pitched 2 degrees below the local horizontal at 35 degrees elevation east of the landmark (approximately 90 seconds from the closest point of approach (CPA) to the landmark). The spacecraft is then given a -0.3-degree per second pitch rate. The pitch rate is maintained for 249 seconds until the spacecraft is in the sleep pitch attitude. The landmark remains in the optics field of coverage for the first 3 minutes. The CSM/LM is then rolled 82 degrees to the sleep attitude. This attitude is held inertial through completion of the fourth revolution. Command and

service module S-band HGA communications will be available from the time of attaining the sleep attitude to loss of MSFN line of sight.

5.1.5 Docked lunar landmark tracking (Figures 8, 9, and 10). - The geometry for lunar landmark tracking is defined by Figures 8 and 9. The acceptable marking region is defined as the area from 35 degrees elevation on either side of the landmark. The period of time the spacecraft remains in the acceptable marking region is on the order of 3 minutes. Marks taken within this region must be equally spaced and at least 25 seconds apart. Five marks are required on each landmark, with a minimum time of 100 seconds required between the first and the last mark. The primary consideration is that the marks be taken over a wide spread of elevation geometry. The scanning telescope (SCT) will be used to acquire the landmark, and the SXT will be used to track the landmark.

The landmark tracking attitude mode to be used for docked lunar landmark tracking is a mode I type. A complete discussion of the lunar landmark tracking attitude modes available for landmark tracking is presented in Reference 6. Mode I tracking consists of an inertial attitude hold with the CSM X-Z plane approximately in the lunar orbit plane. As the spacecraft approaches the landmark, a pitch rate is added to allow the landmark to remain in the optical fields of coverage while the spacecraft is in the acceptable marking region. The geometry for the particular mode I tracking used is presented in Figure 10. The initial inertial attitude is such that the CSM is pitched 2.1 degrees below the local horizontal orientation approximately 90 seconds before the closest point of approach (CPA). A -0.3 degree per second pitch rate is added at 35 degrees elevation and is maintained until the vehicle exits the acceptable marking region approximately 90 seconds after the CPA. At the termination of the pitch rate the CSM X-axis lies approximately 47 degrees below the local horizontal. The landmark enters the SCT field of coverage 148 seconds before the CPA (21 degrees elevation) and enters the SXT field of coverage 112 seconds before the CPA (28.2 degrees elevation). The landmark is still in both the SXT and SCT fields of coverage at the termination of the pitch rate.

To aid the astronaut in landmark tracking, two times, T_1 and T_2, will be updated to the astronaut in real time. T_1 is the g.e.t. when the spacecraft comes across the landmark topocentric horizon. This is primarily an astronaut alert time. T_1 occurs approximately 390 seconds before the CPA to the landmark. T_2 is the g.e.t. to start the pitch rate. T_2 occurs approximately 90 seconds before the CPA.

As a result of the maximum rate limits of the optics shaft and trunnion angles, there are certain zones in the optical coverage area where the optics line of sight cannot keep up with the coverage of the landmark. This occurs when the groundtrack of the optics shaft axis passes close to the landmark. In mission G, the optical blind zone will be avoided by rolling the spacecraft so that the minimum trunnion angle is at least 10 degrees. This maneuver will be added in real time, and is not simulated here. The required roll is small, and the times given above are not

appreciably affected. The optics shaft and trunnion angles given in Table II(c), part 1 are the optics angles required to center the optics line of sight along the vehicle to landmark line of sight at 35 degrees elevation before the CPA. These angles do not reflect the roll maneuver required to avoid the optics blind zone. Detailed shaft and trunnion plots are available for each landmark but will not be presented in this document.

5.1.6 Fifth revolution (Figure 11). - At the start of the fifth revolution, the spacecraft is in the inertially fixed lunar orbit sleep attitude. A 9-hour sleep period is started approximately 27 minutes after the acquisition of MSFN line of sight. The lunar orbit sleep attitude is maintained inertially fixed through the completion of the fifth revolution.

5.1.7 First lunar orbit sleep period (Figures 12, 13, 14, 15, 16, and 17). - The inertial lunar orbit sleep geometry is shown in Figure 12. An inertial attitude hold is used to minimize RCS propellant usage and to provide the required continuous CSM S-band HGA communications when line of sight to the earth exists. Also, RCS quad cold problems must be avoided. The thermal constraints may be avoided by rolling the spacecraft so that quad B is pointed at the sun (after LOI-1 the RCS tank behind quad B is almost full and acts as a heat sink). To decrease the amount of sunlight incident on quad B the spacecraft X-axis is pitched 60 degrees from the normal to the sun. This sleep attitude was flown on mission F after quad A heated up during sleep (the RCS tank behind quad A was almost empty after LOI-1) and proved to work satisfactorily. The inertial attitude is such that the CSM is pitched -120 degrees and rolled 82 degrees from the local horizontal at the subsolar point. The attitude is kept in G&N attitude hold with a ±10-degree deadband throughout the lunar orbit sleep period. The lunar orbit sleep period lasts approximately 9 hours, being terminated in the tenth revolution. The inertial sleep attitude is maintained until the 40 degree roll maneuver for LM S-band antenna check in the tenth revolution. The LM is occupied approximately 5 minutes prior to completion of the tenth revolution.

5.1.8 Eleventh revolution (Figure 18). - At the beginning of the eleventh revolution, the spacecraft is in the inertial LM S-band check attitude and the crew is awake. This attitude is maintained inertially fixed through completion of the eleventh revolution. This attitude satisfies the attitude requirements for a CSM IMU alignment to the updated landing site REFSMMAT which occurs immediately after the CSM/LM enters darkness. The CSM and LM S-band steerable communications will be available from acquisition of MSFN line of sight to loss of MSFN line of sight.

5.1.9 Twelfth revolution (Figure 19). - At the beginning of the twelfth revolution, the spacecraft is in the inertial LM S-band check attitude tude. This attitude is held until approximately 4 minutes after acquisition of MSFN line of sight when the CSM/LM is maneuvered to the landmark tracking attitude. This attitude is held inertially fixed until 35 degrees elevation east of landmark 130 when a -0.3 degree per second pitch rate is initiated. This pitch rate is maintained for 180 seconds until the landmark has passed out of the optics. Then the pitch rate is increased to -0.5 degree per second for approximately 7 minutes. The pitch rate is then terminated with the CSM/LM in the undocking attitude. This attitude is held inertially fixed until the abort guidance system (AGS) calibration test is performed just after the CSM/LM enters sunlight. For the AGS calibration test, the vehicle is yawed 14 degrees out of plane. This attitude is held inertially fixed until the test is completed approximately 4 minutes after the completion of the twelfth revolution. The CSM/LM is then yawed -14 degrees back into the orbital plane to the undocking attitude. This attitude is held inertially fixed until undocking approximately 4 minutes prior to acquisition of MSFN line of sight on the thirteenth revolution. The CSM and LM S-band HGA communications will be available on the twelfth revolution from termination of the tracking pitch rate until loss of MSFN line of sight.

5.2 CSM/LM Undocking to LM Landing

Detailed trajectory and attitude data for both the CSM and LM during the CSM/LM undocking to LM landing portion of the lunar orbit are presented in Table II(c), part 2.

5.2.1 CSM/LM undocking to DOI burn ignition (Figures 20 and 21). - Undocking will occur at 100:15:00 g.e.t., which is approximately 25 minutes prior to the CSM-RCS separation burn. The orientation of the vehicles is such that the LM is ahead of the CSM. The CSM is in-plane, heads up, and pitched 15.0 degrees above the local horizontal. This attitude is the CSM inertial separation burn attitude. Following undocking, the LM will null the relative range rate after a separation distance of 40 to 50 feet is achieved. The CSM will then station keep at this distance while the LM performs a 60-degree positive roll (pilot yaw left) maneuver and a 110-degree positive pitch maneuver. This will place the LM heads down and at an attitude where the crews will be eye to eye. The CMP will then inspect and photograph the LM landing gear and descent engine bell while the LM does a 360-degree roll (pilot yaw) maneuver. Immediately after completion of the inspection, the LM will begin station keeping. The attitude of each spacecraft is held inertially fixed until after the CSM-RCS separation burn cutoff.

Separation is accomplished by the CSM X-axis RCS thrusters applying a ΔV of 2.5 feet per second radially downward. This maneuver is performed at approximately 180 degrees central angle prior to descent orbit insertion (DOI). At separation burn ignition the CSM is in-plane and pitched 90 degrees above the local horizontal (plus X-axis is coincident

with the radius vector). An attitude maneuver should not be required at this time since the CSM undocking attitude was the inertial separation burn attitude. The LM will have performed small translation maneuvers during the LM station keeping phase so that it will be above and slightly ahead of the CSM at separation. This will allow the LM to visually monitor the CSM-RCS separation burn while maintaining an attitude that is favorable for establishing the rendezvous radar (RR) tracking attitude which immediately follows separation. Each spacecraft will be in an attitude favorable for HGA communications during the separation burn.

Following the CSM separation burn, the CSM and LM will be maneuvered (pitched) automatically to the required attitudes for CSM SXT tracking - VHF ranging and LM RR tracking. The necessary tracking attitude points the center of the common coverage of the CSM SXT and RR transponder along the CSM-LM line of sight. The center of common coverage lies 35 degrees from the CSM plus X-axis measured toward the plus Z-axis. Likewise, the center of coverage of the LM tracking light should be pointing along the LM-CSM line of sight. The center of coverage of the tracking light lies along the LM plus Z-axis. This attitude is also the preferred attitude for LM RR coverage. For this tracking period, and for all subsequent CSM/LM tracking except during the powered descent initiation (PDI) tracking phase as discussed in Section 5. 2. 2, the CSM and LM are initially oriented in a heads-down attitude and in a heads-up attitude, respectively. The initial attitudes of the vehicles allow for CSM SXT/RR transponder and LM RR/tracking light line-of-sight maintenance. The amount each vehicle is pitched in order to obtain the preferred track axis (vehicle-to-vehicle look-angles discussed above) is dependent upon the relative positions of the vehicles at the time of separation. Assuming that the LM is 50 feet above and 5 feet ahead of the CSM at separation, the CSM will be pitched approximately 40 degrees, and the LM will be pitched approximately 20 degrees following the CSM separation burn cutoff in order to obtain the preferred track axis.

The CSM and LM will perform an IMU realignment beginning about 5 minutes after sunset. Both vehicles will be in inertial attitude hold during the IMU realignments and will continue in this mode until approximately 6 minutes prior to LM DOI burn ignition. At this time, the CSM will begin an automatic pitch maneuver to the preferred track axis discussed previously in order to monitor the LM descent propulsion system (DPS) DOI burn and to provide radar transponder coverage. Also, at this time, the LM will begin a maneuver to the inertial DOI burn attitude which is a retrograde, in-plane, face-up orientation. The LM DPS DOI burn ignition occurs at 101:38:48 g. e. t.

The attitude of the CSM from acquisition of MSFN line of sight until loss of MSFN line of sight is favorable for HGA communications. The attitude of the LM from the time the LM begins station keeping until loss of MSFN line of sight is favorable for HGA communications.

A relative motion plot of the two spacecraft from separation to DOI is illustrated in Figure 21. The LM is assumed to be approximately 50 feet above and 5 feet ahead of the CSM at separation. The crew procedures information presented in Reference 7 was used to develop the attitude sequences from undocking to DOI.

5.2.2 DOI burn cutoff to PDI burn ignition (Figures 22 and 23). - Following the cutoff of the DPS DOI burn at 101:39:16 g.e.t., the LM maintains the burn orientation in an inertial attitude hold for approximately 2 minutes. At this time, the LM begins maneuvering to the preferred RR tracking attitude described in the previous section. The RR lock-on occurs 3 minutes later and the tracking interval lasts for 2 minutes. At the termination of the tracking period, approximately 101:45:48 g.e.t., the LM maneuvers to the PDI inertial pitch orientation. Five minutes later, the LM begins a 180-degree roll (pilot yaw left) to complete the maneuvers to the PDI attitude. The PDI attitude is defined at pericynthion of the descent orbit by a LM retrograde, local horizontal, and face-down orientation. The LM maintains this orientation in an inertial attitude hold until PDI.

Following DOI cutoff, the CSM continues SXT tracking - VHF ranging operations in a heads-down attitude until shortly before MSFN line-of-sight acquisition for the CSM. At this time, the automatic pitch rate is nulled and the resulting orientation maintained in an inertial attitude hold for approximately 2 minutes. This orientation provides S-band HGA communications at MSFN acquisition and continuously through the 2-minute period. At this time, the CSM will maneuver to a heads-up SXT tracking attitude prior to PDI. The CSM S-band HGA communications are interrupted by this maneuver and will not be regained until after the LM landing. At approximately 4 minutes prior to PDI, the CSM terminates automatic tracking and the resulting orientation maintained in an inertial attitude hold until 1 minute after PDI.

The CSM-LM relative motion for the lunar orbit phase from DOI to LM landing is shown in Figure 23.

5.2.3 PDI burn ignition to LM landing (Figure 24). - PDI occurs at 102:35:14 g.e.t., when the DPS engine is ignitied. The powered descent is a guided burn from pericynthion to landing site 2. Approximately 3 minutes after PDI, the LM rolls through 180 degrees (pilot yaw right) to a face-up orientation. The LM S-band HGA communications are available throughout the powered descent.

At 1 minute after PDI, the CSM initiates a -0.2 degree per second pitch rate. The pitch rate is maintained until after the LM lands to insure SXT tracking throughout the powered descent. The CSM S-band HGA communications are not available until after the LM lands.

5.3 LM Landing to LM Lift-off (CSM Solo Operations)

Detailed trajectory and attitude data for the CSM solo operations from LM landing to LM lift-off are presented in Table II(c), part 3.

5.3.1 LM landing to initiation of fifteenth revolution (Figure 25). - At LM touchdown, which occurs at 102:47:11 g.e.t., the CSM pitch rate of -0.2 degree per second is continued. The CSM attitude, with respect to the local horizontal orientation, is a pitch of -77.7 degrees.

The CSM pitch rate is terminated at 103:00:00 g.e.t., and the resulting attitude held inertial. This inertial attitude satisfies the requirements for the IMU realignment to the landing site REFSMMAT, which occurs approximately 7 minutes after LM touchdown.

The CSM attitude is held inertially fixed through the completion of the fourteenth revolution. Command and service module S-band HGA communications will be available from the acquisition after LM touchdown prior to entering lunar umbra until loss of MSFN line of sight.

5.3.2. Undocked lunar landmark tracking (Figure 26). - During the undocked landmark tracking periods, LM blockage, which obscured part of the CSM optics during docked sightings, is no longer a problem. For this reason, mode III type landmark tracking will be used for the undocked landmark sightings (Reference 6). The spacecraft attitude, with respect to the local horizontal orientation during undocked sightings, is a pitch of -22 degrees. The geometry of the mode III type landmark tracking is shown in Figure 26. The landmark enters the SCT field of coverage 100 seconds before the CPA (32 degrees elevation) and exits the SXT field of coverage 56 seconds past the CPA (49.7 degrees elevation). The landmark remains in the SXT field of coverage for 146 seconds within the acceptable mark region. This should be adequate time to obtain the required five marks. It should be pointed out, if trouble occurs in obtaining the marks, additional tracking time can be made available by adding a small pitch rate near the end of the tracking period. The optical blind zone constraint may be satisfied, as in the docked sightings, by rolling the spacecraft as the landmark is approached to assure a minimum trunnion angle of at least 10 degrees.

5.3.3 Fifteenth revolution (Figure 27). - At the beginning of the fifteenth revolution, the CSM is in the inertially fixed IMU realignment attitude. Approximately 5 minutes prior to acquisition of MSFN line of sight, the CSM is maneuvered to the mode III type landmark tracking attitude. The CSM attitude, with respect to the local horizontal orientation, is a pitch of -22 degrees. This attitude is held locally fixed through the completion of tracking of the LM. At this time, approximately 6 minutes before entering darkness, the CSM maneuvers to the plane-change attitude, yawed 45 degrees. This attitude is held inertially fixed through the completion of the fifteenth revolution. Approximately 9 minutes after entering darkness, the IMU is aligned to the plane change REFSMMAT. CSM

S-band HGA communications will be available from acquisition of MSFN line of sight until loss of MSFN line of sight, except when tracking the LM during landmark tracking.

5.3.4 Sixteenth revolution (Figure 28). - At the beginning of the sixteenth revolution, the CSM is in the inertially fixed IMU realignment attitude. This attitude is held inertially fixed until approximately 10 minutes prior to entering darkness, when the CSM is maneuvered to the plane-change burn attitude. The CSM attitude, with respect to the local horizontal orientation, is a pitch of 163.3 degrees, a yaw of 86.8 degrees, and a roll of -64.2 degrees. The CSM plane-change attitude is held inertially fixed through the plane-change burn which occurs at 107:05:33 g.e.t. The CSM plane-change burn attitude is held inertially fixed until approximately 5 minutes after the burn cutoff, when the CSM maneuvers to the attitude for IMU realignment to the lift-off REFSMMAT. The CSM attitude, with respect to the local horizontal orientation, is a pitch of -102.1 degrees, a yaw of 45.1 degrees, and a roll of -64.4 degrees. The IMU realignment begins approximately 10 minutes prior to loss of MSFN line of sight. The CSM IMU realignment attitude is held inertially fixed until approximately 10 minutes after loss of MSFN line of sight, when the CSM maneuvers to the lunar orbit sleep attitude. This attitude is held inertially fixed through the completion of the sixteenth revolution. The CSM S-band HGA communications will be available from the acquisition of MSFN line of sight until the loss of MSFN line of sight.

5.3.5 Second lunar orbit sleep (Figures 29 and 30). - The CSM attitude during the second lunar orbit sleep period will be the same attitude as that for the first lunar orbit sleep period as illustrated in Figure 12. This sleep period consists of a 4-hour rest period, and a 4-hour period in which strip photography and COAS tracking of the LM are planned for the CSM, followed by another 4-hour rest period and terminating at the time of the CSM maneuver to support lift-off. The inertial lunar orbit sleep attitude is such that the CSM is pitched -120 degrees and rolled 81.5 degrees from the local horizontal orientation at the subsolar point. The longitude used in calculating the attitude is the longitude at the subsolar point in the twentieth revolution. The inertial sleep attitude is maintained through the completion of the twenty-fourth revolution. Command and service module S-band HGA communications will be available from acquisition of MSFN line of sight to loss of MSFN line of sight in each vehicle revolution except during strip photography and COAS tracking of the LM in the nineteenth revolution.

5.3.6 Nineteenth revolution (Figure 31). - At the beginning of the nineteenth revolution, the CSM is in the inertially fixed lunar orbit sleep attitude. Approximately 11 minutes prior to entering sunlight, the CSM maneuvers to the locally fixed lunar surface observation attitude. The CSM attitude with respect to the local horizontal orientation is a pitch of -78 degrees and a roll of 180 degrees. This attitude is held locally fixed through the completion of the nineteenth revolution. The CSM S-band HGA

communications will be available from acquisition of MSFN line of sight until loss of MSFN line of sight.

5.3.7 Twentieth revolution (Figure 32). - At the beginning of the twentieth revolution, the CSM is in the locally fixed lunar surface observation attitude. Approximately 14 minutes after acquisition of MSFN line of sight, the CSM is maneuvered to the initial COAS tracking attitude. The CSM attitude with respect to the local horizontal orientation is a pitch of -40 degrees. This attitude is held locally fixed for 10 minutes when line-of-sight maintenance to the LM begins. Line-of-sight maintenance is continued for 2 minutes when the CSM maneuvers to the lunar surface observation attitude again. This attitude is held locally fixed through the completion of the twentieth revolution. The CSM S-band HGA communications will be available from acquisition of MSFN line of sight until loss of MSFN line of sight except during COAS tracking of LM.

5.3.8 Twenty-first through twenty-fourth revolutions (Figures 33, 34, 35, and 36). - At the beginning of the twenty-first revolution, the CSM is in the locally fixed lunar surface observation attitude. Approximately 12 minutes prior to entering darkness, the CSM is again maneuvered to the lunar orbit sleep attitude. The CSM attitude with respect to the local horizontal orientation is a pitch of -47.4 degrees and a roll of 81.5 degree 81.5 degrees. This attitude is held inertially through the twenty-first revolution and until the maneuver to support LM lift-off in the twenty-fifth revolution. The CSM S-band HGA communications will be available from the maneuver to the lunar orbit sleep attitude until the maneuver to support LM lift-off whenever MSFN line of sight exists.

5.3.9 Twenty-fifth revolution to LM lift-off (Figure 37). - At the beginning of the twenty-fifth revolution, the CSM is in the inertially fixed lunar orbit sleep attitude. The attitude is maintained inertially fixed until approximately 20 minutes prior to LM lift-off, when the CSM is maneuvered to the attitude to support LM lift-off. At LM lift-off, the CSM is pitched 60 degrees below the local horizontal orientation. The CSM S-band HGA communications will be available from acquisition of MSFN line of sight until the maneuver to the LM lift-off support attitude.

5.4 LM Lift-off to CSM/LM Docking

Detailed trajectory and attitude data for both the CSM and LM during the LM lift-off to CSM/LM docking portion of the lunar orbit are presented in Table II(c), part 4.

5.4.1 Lift-off to insertion burn cutoff (Figure 38). - Ascent ignition occurs at 124:23:21 g.e.t. The powered ascent is a guided ascent propulsion subsystem (APS) burn to a targeted 9-nautical mile by 45-nautical mile ellipse. The LM orientation during the burn provides LM S-band HGA communications.

Prior to ascent ignition, the CSM is oriented to provide RR tracking for ascent monitoring. At ascent ignition, the CSM initiates a -0.2 degree per second pitch rate to insure RR tracking throughout the ascent burn. The CSM S-band HGA communications are available approximately 5 minutes after ascent ignition.

5.4.2 Insertion burn cutoff to CDH burn ignition (Figures 39 and 40). - Cutoff of the APS ascent burn occurs at 124:30:44 g.e.t., with the LM trailing the CSM in a 9-nautical mile perilune by a 45-nautical mile apolune orbit as required for CSM-LM rendezvous. The CSM-LM relative motion during rendezvous is shown in Figure 40. At ascent burn termination, the LM orients to an inertially fixed attitude suitable for performing an IMU realignment which begins 5 minutes later. Following the realignment, the LM orients to the heads-up RR tracking attitude in preparation for a tracking period starting 25 minutes after insertion.

The CSM at insertion is nominally 16 degrees ahead of the LM in central angle. The -0.2 degree per second pitch rate which was initiated at LM lift-off is terminated 5 minutes after insertion, and an inertial IMU realignment attitude is established. The realignment is scheduled to last 5 minutes, after which the CSM orients for a period of VHF ranging.

Both spacecraft terminate tracking at 125:11:19 g.e.t. or 10 minutes prior to the coelliptic sequence initiation (CSI) burn. The LM continues to automatically track the CSM along the LM plus Z-axis, since the CSI thrust direction is along the LM to CSM line of sight with the Z-axis thrusters. All nominal LM rendezvous burns (with the exception of constant delta altitude (CDH) are similarly planned.

The CSM, in preparing for the CSI maneuver, orients to the inertial mirror image (MI) CSI burn attitude. The MI burn attitude is a means of providing CSM backup capability for the LM rendezvous burns from CSI to the final braking maneuvers. The MI burn attitude involves aligning the CSM propulsion system (RCS or SPS) in a thrusting direction opposite the LM burn orientation. Ignition for the MI burn is scheduled 3 minutes after nominal time of LM ignition.

The LM CSI burn occurs in darkness and out of earth line of sight for both spacecraft. CSM and LM HGA communications are acceptable in terms of the respective spacecraft attitude profile from insertion to loss of earth line of sight.

CSI ignition occurs at 125:21:19 g.e.t., with a burn time of approximately 45 seconds. The LM attitude for the burn is pitched approximately 90 degrees from the local horizontal. This attitude corresponds to a heads-up, face-forward direction for the crew and also maintains the CSM line of sight along the LM Z-axis.

The MI burn attitude for the CSM, which is held inertially fixed until the burn is confirmed, is retrograde and heads-down (180 degrees pitch

with respect to the local horizontal). The CSM next maneuvers to prepare for a 39-minute period of VHF ranging beginning 6 minutes after the burn.

The LM continues the line-of-sight maintenance program after the burn and is consequently prepared for the following RR tracking period.

The CSM and LM acquire line of sight to MSFN approximately 27 and 30 minutes, respectively, after starting the tracking period. The CSM attitude profile from MSFN acquisition to termination of the tracking period is incompatible with HGA pointing requirements. A 180-degree roll maneuver is performed at the end of the tracking period with the resulting attitude inertially fixed in order to acquire MSFN through the CSM steerable antenna. This attitude is maintained through the completion of the LM CDH maneuvers.

The LM HGA communications during the period from MSFN line-of-sight acquisition to completion of the CDH burn is acceptable. The LM orients to the inertial CDH burn attitude after termination of CSM tracking. The LM burn attitude at ignition (126:19:37 g. e. t.) is pitched up 74. 9 degrees from the local horizontal. The RCS minus X-axis thrusters perform the burn which lasts for 2 seconds. For this simulation, the required CDH burn did not necessitate a backup CSM maneuver. As noted previously, the CSM inertially holds the attitude at the end of the preceding tracking period (after a 180-degree roll) until the start of the next LM tracking period.

5. 4. 3 CDH burn cutoff to CSM/LM docking (Figure 41). - The CSM and LM begin another tracking period 4 minutes after the CDH burn. Both spacecraft hold their attitudes at burn termination until orienting to the required tracking attitude. The tracking period is 19 minutes in duration and is followed by terminal phase initiation (TPI) burn preparations.

The CSM orients to the inertial MI TPI burn attitude as part of the pre-TPI operations. This attitude results in a local horizontal pitch of -151. 7 degrees at TPI ignition which places the LM line of sight along the CSM X-axis. The CSM maintains the MI burn attitude until the LM TPI burn is verified as nominal.

The LM, in preparing for the TPI burn, continues CSM line-of-sight maintenance as noted previously. The burn is performed using the Z-axis thrusters with ignition at 126:58:08 g. e. t. and a burn time of 38 seconds. The burn occurs within MSFN coverage and approximately 23 minutes after the LM enters darkness. MSFN line-of-sight is lost approximately 6 minutes after the burn.

S-band HGA communications for the CSM and LM are satisfactory throughout the period from the CDH burn to loss of MSFN by lunar occultation.

Following the TPI burn, both spacecraft begin another period of tracking. The CSM orients to the required tracking attitude which is initially heads-down. The LM is initially heads-up with the Z-axis pitched up 26 degrees from the local horizontal. As a result of the LM catchup rate following TPI, the CSM and LM line-of-sight maintenance for tracking eventually produces a heads-up attitude for the CSM and a heads-down attitude for the LM. This relative orientation is maintained through the completion of the rendezvous and docking maneuvers.

The initial LM braking burn occurs at 127:39:24 g. e. t. with the CSM and LM 3000 feet apart. The braking maneuver at the 1-nautical mile separation distance was not required in the rendezvous simulation.

After the first braking maneuver, the CSM orients to an LM X-axis boresight alignment attitude and establishes a manual pitch rate to maintain this alignment for the remainder of the rendezvous. The LM continues the automatic RR tracking along the LM Z-axis during the coasts between the braking maneuvers. All braking burns are directed towards the CSM along the LM Z-axis.

The final LM braking burn occurs at a CSM-LM relative range of 100 feet. At cutoff, the range is approximately 90 feet and the closing rate is 0. 22 foot per second. The LM continues holding the CSM line of sight along the Z-axis until a separation distance of 50 feet is reached. The LM then pitches 90 degrees to point the plus X-axis towards the CSM in preparation for docking. Both spacecraft then fly formation while the CSM performs the final closing maneuvers. These include rolling the CSM to properly align the docking index.

Docking is assumed to be completed at 128:00:00 g. e. t. The CSM/LM docking attitude was designed to satisfy a lighting requirement that the angle between the active vehicle plus X-axis and sun vector be greater than 90 degrees. Consequently, nominal HGA coverage for either the CSM or LM is not provided upon MSFN line-of-sight acquisition.

5. 5 CSM/LM Docking to TEI

Detailed trajectory and attitude data for the CSM/LM docking to TEI portion of lunar orbit are presented in Table II(c), part 5.

5. 5. 1 CSM/LM docking to completion of twenty-seventh revolution (Figure 42). - The CSM/LM docking maneuver is completed at 128:00:00 g. e. t. The docking attitude is maintained inertially fixed while postdocking checks are initiated. The spacecraft is then maneuvered to the LM jettison attitude. This attitude is held inertially fixed through the completion of the twenty-seventh revolution while the LM crew starts preparations to leave the LM.

5.5.2 Twenty-eighth revolution (Figure 43). - At the beginning of the twenty-eighth revolution, the CSM/LM is in the inertially-fixed LM jettison attitude. This attitude is maintained inertially fixed through the completion of the twenty-eighth revolution while the LM crew continued preparations for leaving the LM.

5.5.3 Twenty-ninth revolution (Figure 44). - At the beginning of the twenty-ninth revolution, the CSM/LM is in the inertially-fixed LM jettison attitude. The LM crew has returned to the CSM, and preparation is being made for LM jettison. The LM jettison attitude is an inertial attitude that places the CSM in the local horizontal orientation at 90 degrees east selenographic longitude. The LM is jettisoned posigrade so that the LM moves initially above and ahead of the CSM and then falls behind the CSM and continues to fall further behind. The nominal time of LM jettison is 131:53:05 g.e.t. The LM jettison attitude does not provide CSM S-band HGA communications.

Following LM jettison, the jettison attitude is held inertially fixed for approximately 7 minutes. The CSM is then maneuvered to the transearth injection (TEI) burn attitude rolled 180 degrees. This attitude is maintained inertial through the completion of the twenty-ninth revolution. CSM S-band HGA communications will be available from the maneuver to the transearth injection (TEI) attitude rolled 180 degrees to the loss of MSFN line of sight.

5.5.4 Thirtieth revolution (Figure 45). - At the beginning of the thirtieth revolution, the CSM is in the inertially fixed TEI burn attitude rolled 180 degrees. This attitude satisfies the requirements for an IMU realignment to the lift-off REFSMMAT which occurs about 6 minutes after the CSM enters darkness. This attitude is maintained inertially fixed until the CSM is rolled 180 degrees to the TEI burn attitude, approximately 24 minutes before TEI burn ignition. This attitude is held inertially fixed through the completion of the thirtieth revolution. CSM S-band HGA communications will be available from acquisition of MSFN line of sight to loss of MSFN line of sight.

5.5.5 Start of thirty-first revolution to TEI burn ignition (Figure 46). - Shortly after the CSM begins the thirty-first revolution, the TEI burn occurs. The TEI burn is the major SPS burn which boosts the CSM from its approximately 60-nautical mile circular lunar orbit into the transearth trajectory. The burn is performed with the CSM in an essentially posigrade attitude, and the crew is heads down to afford visual reference with the lunar surface. TEI burn ignition occurs at 135:24:34 g.e.t.

6. TRANSEARTH ATTITUDE PROFILE

The transearth phase of the mission begins at TEI burn termination and ends at earth atmospheric entry of the CM. Most of the major events occurring in this phase (midcourse corrections, PTC, IMU realignments, and cislunar navigation) are similar in nature to the translunar coast. Those events unique to the transearth phase, which will be discussed in this section, are the attitude sequences following TEI and prior to entry. The spacecraft attitude data for the transearth coast phase are presented in Table II(d).

6.1 Post-TEI Sequence of Events

Following TEI cutoff at 135:27:03 g. e. t., the CSM maneuvers to an inertial attitude that provides the crew with visual observation of the lunar surface. This orientation consists of the CSM plus X-axis pointing radially inward and the plus Z-axis forward in the trajectory plane. MSFN communications through the HGA at acquisition of signal is also provided with this attitude. Earth line of sight is acquired at 135:35:21 g. e. t. An IMU realignment begins at approximately 135:40:00 g. e. t. during which the IMU reference system is realigned to the PTC REFSMMAT defined in Section 4. The completion of the realignment marks the termination of post-TEI activities.

6.2 Preentry Sequence of Events

The start of the preentry attitude sequence is assumed at 191:00:00 g. e. t. when the spacecraft IMU is aligned to the entry REFSMMAT. This inertial reference system corresponds to the nominal CM entry attitude of 156 degrees positive pitch from the local horizontal at the nominal time of entry with the body X-Z axes in-plane. A midcourse correction is scheduled at 192:00:00 g. e. t., if required. One hour and 10 minutes later, at 193:10:00 g. e. t., the CSM orients to the entry attitude and performs a star check to verify the attitude. An IMU realignment is performed at 193:35:00 g. e. t. Upon completion of the realignment, the spacecraft prepares for the CM/SM separation maneuver which occurs at 194:40:00 g. e. t. The CM/SM separation attitude is shown in Figure 47. The spacecraft is yawed 45 degrees for separation to minimize CM-SM recontact probability during entry. After completing the separation maneuver, the CM reorients to the nominal entry attitude in preparation for entry which occurs at 195:05:03 g. e. t. The CM entry attitude is presented in Figure 48.

Table I. Mission G Event Timeline
(a) Translunar

Mission Time (hr:min:sec)	Event
02:49:46	TLI cutoff, inertial attitude hold
02:50:06	S-IVB maneuver to local horizontal orientation, rolled 180 degrees, local attitude hold
03:05:00	S-IVB maneuver to CSM/S-IVB separation attitude, inertial attitude hold
03:15:00	CSM/S-IVB separation
03:17:00	CSM null separation rate, pitch 180 degrees and roll -60 degrees for docking
03:25:00	CSM/LM docking
04:09:45	LM ejection
04:20:00	CSM pitch -75 degrees and roll to visually acquire S-IVB
04:39:45	SPS evasive maneuver burn ignition
04:39:48	Evasive maneuver burn cutoff, inertial attitude hold
05:30:00	Begin IMU realignment
06:00:00	Begin star-earth horizon navigation sightings
10:40:00	Begin IMU realignment
11:45:00	SPS midcourse burn ignition
12:00:00	Begin IMU realignment, change to PTC REFSMMAT
12:20:00	Begin PTC
24:10:00	Terminate PTC, begin IMU realignment
24:30:00	Begin star-earth horizon navigation sightings
26:45:00	Midcourse correction
27:00:00	Begin PTC
53:00:00	Terminate PTC, begin IMU realignment
53:55:00	Midcourse correction
54:00:00	Begin PTC
70:00:00	Terminate PTC, begin IMU realignment to landing site REFSMMAT
70:55:00	Midcourse correction

Table I. Mission G Event Timeline
(a) Translunar (Continued)

Mission Time (hr:min:sec)	Event
73:32:00	Begin IMU realignment
74:05:00	Maneuver to LOI-1 burn attitude, inertial attitude hold
74:10:00	Roll 60 deg for MSFN
74:15:00	Roll -60 deg to LOI-1 burn attitude
74:25:00	Begin -0.3 deg/sec pitch rate
74:55:00	Terminate pitch rate in LOI-1 burn attitude, inertial attitude hold
75:45:34	Lose MSFN line of sight

Table I. Mission G Event Timeline
(b) Lunar Orbit

Mission Time (hr:min:sec)	Event
75:54:28	LOI-1 ignition
76:00:27	LOI-1 cutoff, inertial attitude hold
76:02:00	Maneuver to lunar observation attitude, local attitude hold
76:19:01	Acquire MSFN line of sight
77:02:03	Enter lunar umbra
77:43:57	Lose MSFN line of sight
77:48:10	Enter sunlight
78:27:08	Acquire MSFN line of sight
79:10:00	Terminate orbital pitch rate, inertial attitude hold
79:10:23	Enter lunar umbra
79:15:00	Begin IMU realignment
79:35:00	Maneuver to LOI-2 burn attitude, inertial attitude hold
79:52:09	Lose MSFN line of sight
79:56:32	Enter sunlight
80:09:30	LOI-2 ignition
80:09:46	LOI-2 cutoff, inertial attitude hold
80:15:00	Maneuver to lunar observation attitude, local attitude hold
80:36:57	Acquire MSFN line of sight
81:09:00	Terminate orbital pitch rate, inertial attitude hold
81:09:55	Enter lunar umbra
81:10:00	Begin IMU realignment
81:48:38	Lose MSFN line of sight
81:55:54	Enter sunlight
82:26:00	Maneuver to landmark tracking attitude, inertial attitude hold

Table I. Mission G Event Timeline
(b) Lunar Orbit (Continued)

Mission Time (hr:min:sec)	Event
82:35:19	Acquire MSFN line of sight
82:46:18	Begin -0.3 deg/sec pitch rate for landmark tracking
82:50:27	Terminate pitch rate, roll 82 deg to sleep attitude, inertial attitude hold
83:08:24	Enter lunar umbra
83:46:48	Lose MSFN line of sight
83:54:26	Enter sunlight
84:33:20	Acquire MSFN line of sight
85:00:00	Start crew sleep period
85:06:50	Enter lunar umbra
85:45:06	Lose MSFN line of sight
85:52:49	Enter sunlight
86:31:36	Acquire MSFN line of sight
87:05:18	Enter lunar umbra
87:43:19	Lose MSFN line of sight
87:51:23	Enter sunlight
88:29:55	Acquire MSFN line of sight
89:03:46	Enter lunar umbra
89:41:24	Lose MSFN line of sight
89:49:45	Enter sunlight
90:28:07	Acquire MSFN line of sight
91:02:13	Enter lunar umbra
91:39:49	Lose MSFN line of sight
91:48:19	Enter sunlight
92:26:27	Acquire MSFN line of sight
93:00:39	Enter lunar umbra
93:37:54	Lose MSFN line of sight
93:46:41	Enter sunlight

Table I. Mission G Event Timeline
(b) Lunar Orbit (Continued)

Mission Time (hr:min:sec)	Event
94:00:00	Terminate sleep period
94:24:01	Acquire MSFN line of sight
94:59:08	Enter lunar umbra
95:00:00	Roll 40 deg for LM S-band steerable antenna check, inertial attitude hold
95:35:31	Lose MSFN line of sight
95:45:15	Enter sunlight
95:52:00	LM occupied
96:22:12	Acquire MSFN line of sight
96:57:33	Enter lunar umbra
97:00:00	Begin IMU realignment
97:33:55	Lose MSFN line of sight
97:43:37	Enter sunlight
98:20:34	Acquire MSFN line of sight
98:25:00	Maneuver to landmark tracking attitude, inertial attitude hold
98:45:10	Begin -0.3 deg/sec pitch rate for landmark tracking
98:48:10	Begin -0.5 deg/sec pitch rate
98:54:55	Terminate pitch rate in undocking attitude, inertial attitude hold
98:56:02	Enter lunar umbra
99:00:00	Deploy LM landing gear
99:32:02	Lose MSFN line of sight
99:42:12	Enter sunlight
99:46:00	Maneuver to AGS calibration attitude, inertial attitude hold
99:57:00	Maneuver to undocking attitude, inertial attitude hold
100:15:00	Undocking, inertial attitude hold
100:17:19	LM maneuver to inspection attitude, inertial attitude hold except for 360-deg roll (pilot yaw) maneuver

Table I. Mission G Event Timeline
(b) Lunar Orbit (Continued)

Mission Time (hr:min:sec)	Event
100:18:40	CSM, LM acquire MSFN line of sight
100:20:19	LM begins station keeping, inertial attitude hold
100:39:50	CSM separation burn ignition, inertial attitude hold
100:40:05	CSM separation burn cutoff, inertial attitude hold
100:45:10	CSM maneuvers to SXT tracking - VHF ranging attitude, LM maneuvers to RR tracking attitude, line-of-sight maintenance
100:54:28	CSM enters lunar umbra
100:54:30	LM enters lunar umbra
101:00:00	CSM and LM begin IMU realignment, inertial attitude hold
101:30:27	CSM loses MSFN line of sight
101:30:30	LM loses MSFN line of sight
101:34:00	LM maneuvers to DOI burn attitude, inertial attitude hold
101:35:21	CSM maneuvers to SXT tracking - VHF ranging attitude, line-of-sight maintenance
101:38:48	LM DOI burn ignition, inertial attitude hold
101:39:16	LM DOI burn cutoff, inertial attitude hold
101:40:42	CSM enters sunlight
101:40:46	LM enters sunlight
101:40:48	LM maneuvers to RR tracking attitude
101:43:48	LM RR tracking attitude lock-on, line-of-sight maintenance
101:45:48	LM terminates tracking, inertial attitude hold
101:53:48	LM pitches down to PDI pitch orientation, inertial attitude hold

Table I. Mission G Event Timeline
(b) Lunar Orbit (Continued)

Mission Time (hr:min:sec)	Event
101:58:48	LM 180-deg roll (pilot yaw left) to PDI attitude, inertial attitude hold
102:16:30	CSM acquires MSFN line of sight, terminates automatic tracking, inertial attitude hold
102:18:30	CSM maneuvers to heads-up SXT tracking - VHF ranging attitude, line-of-sight maintenance
102:18:35	LM acquires MSFN line of sight
102:31:14	CSM terminates automatic tracking, inertial attitude hold
102:35:14	LM PDI burn ignition
102:36:14	CSM begins -0.2 deg/sec pitch rate to insure SXT tracking
102:38:14	LM 180-deg roll (pilot yaw right)
102:47:11	LM landing, CSM continues -0.2 deg/sec pitch rate
102:52:56	CSM enters lunar umbra
103:00:00	CSM terminates pitch rate; begins IMU realignment, inertial attitude hold
103:28:34	CSM loses MSFN line of sight
103:39:10	CSM enters sunlight
104:10:00	CSM maneuvers to LM tracking attitude, local attitude hold
104:14:54	CSM acquires MSFN line of sight
104:46:00	CSM maneuvers to plane change attitude, yawed 45 deg, inertial attitude hold
104:51:25	CSM enters lunar umbra
105:00:00	CSM begins IMU realignment
105:26:22	CSM loses MSFN line of sight
105:37:36	CSM enters sunlight
106:12:57	CSM acquires MSFN line of sight

Table I. Mission G Event Timeline
(b) Lunar Orbit (Continued)

Mission Time (hr:min:sec)	Event
106:40:00	CSM maneuvers to plane change attitude, inertial attitude hold
106:49:51	CSM enters lunar umbra
107:05:33	CSM plane change burn
107:10:00	CSM maneuvers to IMU realignment attitude, inertial attitude hold
107:15:00	CSM begins IMU realignment
107:24:41	CSM loses MSFN line of sight
107:35:00	CSM maneuvers to sleep attitude, inertial attitude hold
107:36:12	CSM enters sunlight
108:11:11	CSM acquires MSFN line of sight
108:48:12	CSM enters lunar umbra
109:23:00	CSM loses MSFN line of sight
109:34:34	CSM enters sunlight
110:09:28	CSM acquires MSFN line of sight
110:46:48	CSM enters lunar umbra
111:21:16	CSM loses MSFN line of sight
111:33:08	CSM enters sunlight
112:07:43	CSM acquires MSFN line of sight
112:45:08	CSM enters lunar umbra
113:19:16	CSM loses MSFN line of sight
113:20:00	CSM maneuvers to lunar surface observation attitude, local attitude hold
113:31:31	CSM enters sunlight
114:05:54	CSM acquires MSFN line of sight
114:20:09	CSM maneuvers to inertial, COAS tracking attitude, local attitude hold
114:30:09	CSM COAS tracking of LM
114:32:09	CSM maneuvers to lunar surface observation attitude, local attitude hold

Table I. Mission G Event Timeline
(b) Lunar Orbit (Continued)

Mission Time (hr:min:sec)	Event
114:43:43	CSM enters lunar umbra
115:17:41	CSM loses MSFN line of sight
115:30:04	CSM enters sunlight
116:04:17	CSM acquires MSFN line of sight
116:30:00	CSM maneuvers to sleep attitude, inertial attitude hold
116:42:04	CSM enters lunar umbra
117:15:49	CSM loses MSFN line of sight
117:28:27	CSM enters sunlight
118:02:23	CSM acquires MSFN line of sight
118:40:38	CSM enters lunar umbra
119:14:05	CSM loses MSFN line of sight
119:27:00	CSM enters sunlight
120:00:02	CSM acquires MSFN line of sight
120:39:00	CSM enters lunar umbra
121:11:45	CSM loses MSFN line of sight
121:25:24	CSM enters sunlight
121:58:19	CSM acquires MSFN line of sight
122:37:33	CSM enters lunar umbra
123:09:51	CSM loses MSFN line of sight
123:23:56	CSM enters sunlight
123:56:29	CSM acquires MSFN line of sight
124:03:00	CSM maneuvers to support LM lift-off, inertial attitude hold
124:23:21	LM lift-off, CSM initiates -0.2 deg/sec pitch rate for RR tracking
124:30:44	Insertion burn cutoff, inertial attitude hold
124:35:44	CSM and LM begin IMU realignment
124:35:58	CSM enters lunar umbra
124:36:49	LM enters lunar umbra
124:40:44	CSM completes IMU realignment, begins VHF ranging

Table I. Mission G Event Timeline
(b) Lunar Orbit (Continued)

Mission Time (hr:min:sec)	Event
124:55:44	LM completes IMU realignment, begins RR tracking
125:08:13	CSM loses MSFN line of sight
125:10:06	LM loses MSFN line of sight
125:11:19	CSM and LM terminate VHF ranging and RR tracking, respectively; CSM maneuvers to MI CSI burn attitude, inertial attitude hold; LM continues line-of-sight maintenance of CSM along LM Z-axis
125:21:19	CSI burn ignition
125:22:04	CSI burn cutoff, LM continues line-of-sight maintenance of CSM along LM Z-axis
125:22:24	CSM enters sunlight
125:25:50	LM enters sunlight
125:28:04	CSM and LM begin VHF ranging and RR tracking, respectively
125:54:45	CSM acquires MSFN line of sight
125:57:41	LM acquires MSFN line of sight
126:07:37	CSM and LM terminate VHF ranging and RR tracking, respectively; CSM rolls 180 deg from VHF ranging attitude for HGA communications, inertial attitude hold; LM maneuvers to CDH burn attitude, inertial attitude hold
126:19:37	CDH burn ignition
126:19:39	CDH burn cutoff, inertial attitude hold
126:23:39	CSM and LM begin VHF ranging and RR tracking, respectively.
126:34:28	CSM enters lunar umbra
126:34:42	LM enters lunar umbra
126:42:39	CSM and LM terminate VHF ranging and RR tracking, respectively; CSM maneuvers to MI TPI burn attitude, inertial attitude hold; LM continues line-of-sight maintenance of CSM along LM Z-axis

Table I. Mission G Event Timeline
(b) Lunar Orbit (Continued)

Mission Time (hr:min:sec)	Event
126:58:08	TPI burn ignition
126:58:30	TPI burn cutoff, CSM and LM begin SXT tracking - VHF ranging and RR tracking, respectively
127:05:58	LM loses MSFN line of sight
127:06:25	CSM loses MSFN line of sight
127:20:47	CSM enters sunlight
127:21:18	LM enters sunlight
127:39:24	First LM braking burn ignition (CSM-LM range = 3000 ft)
127:39:35	Braking burn cutoff, CSM maneuvers to point X-axis along CSM to LM line of sight, begins line-of-sight maintenance; LM continues Z-axis line-of-sight maintenance to CSM
127:40:37	Second LM braking burn ignition (CSM-LM range = 1500 ft)
127:40:46	Braking burn cutoff, CSM and LM continue line-of-sight maintenance
127:42:16	Third LM braking burn ignition (CSM-LM range = 500 ft)
127:42:20	Braking burn cutoff, CSM and LM continue line-of-sight maintenance
127:43:35	Fourth LM braking burn ignition (CSM-LM range = 100 ft)
127:43:39	Braking burn cutoff (CSM-LM range = 90ft, range rate = -0.2 ft/sec), CSM and LM continue line-of-sight maintenance
127:47:00	CSM and LM maneuver to docking attitude (CSM-LM range = 50 ft), begin station-keeping
127:52:44	CSM and LM acquire MSFN line of sight
128:00:00	CSM/LM docking (CSM active), inertial attitude hold

Table I. Mission G Event Timeline
(b) Lunar Orbit (Continued)

Mission Time (hr:min:sec)	Event
128:06:00	Maneuver to LM jettison attitude, inertial attitude hold
128:32:52	Enter lunar umbra
129:04:37	Lose MSFN line of sight
129:19:17	Enter sunlight
129:50:55	Acquire MSFN line of sight
130:31:24	Enter lunar umbra
131:02:40	Lose MSFN line of sight
131:17:47	Enter sunlight
131:49:08	Acquire MSFN line of sight
131:53:05	LM jettison
132:00:00	Maneuver to TEI burn attitude rolled 180 deg, inertial attitude hold
132:29:43	Enter lunar umbra
133:00:44	Lose MSFN line of sight
133:16:12	Enter sunlight
133:47:05	Acquire MSFN line of sight
134:28:14	Enter lunar umbra
134:34:00	Begin IMU realignment
134:59:02	Lose MSFN line of sight
135:00:00	Maneuver to TEI burn attitude, inertial attitude hold
135:14:41	Enter sunlight
135:24:34	TEI burn ignition

Table I. Mission G Event Timeline
(c) Transearth

Mission Time (hr:min:sec)	Event
135:27:03	TEI cutoff, maneuver to lunar surface observation attitude (CSM plus X-axis down and plus Z-axis forward), inertial attitude hold
135:35:21	Acquire MSFN line of sight
135:40:00	Begin IMU realignment, change to PTC REFSMMAT
136:00:00	Begin PTC
149:20:00	Terminate PTC, begin IMU realignment
150:25:00	Midcourse correction 5
150:30:00	Resume PTC
171:05:00	Terminate PTC, begin IMU realignment
172:00:00	Midcourse correction 6
172:10:00	Resume PTC
191:00:00	Terminate PTC, begin IMU realignment, change to entry REFSMMAT
192:00:00	Midcourse correction 7
193:10:00	Maneuver to entry attitude, inertial attitude hold
193:35:00	Begin IMU realignment
194:50:00	CM/SM separation
195:05:03	Entry interface

Table II. Spacecraft Attitude and Trajectory Data
(a) Earth Orbit

Mission Time (hr:min:sec)	Event	Geographic Position			Local Horizontal Attitude			IMU Gimbal Angles		
		Altitude* (n mi)	Latitude* (deg)	Longitude* (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)
00:11:53	Earth orbit insertion, begin inertial attitude hold	103.3	32.7	-52.5	0.0	0.0	180.0	-26.9	0.6	-179.2
00:12:04	Begin local attitude hold	103.3	32.7	-53.0	0.0	0.0	180.0	-37.4	0.6	-179.2
02:44:26	Initiate TLI burn	98.5	-4.1	174.0	0.0	0.0	180.0	69.7	0.1	178.7

*Altitude is measured with respect to the Fischer reference ellipsoid; latitude and longitude are measured positive north of the equator and east from the Greenwich meridian, respectively.

Table II. Spacecraft Attitude and Trajectory Data
(b) Translunar

Mission Time (hr:min:sec)	Event	IMU Gimbal Angles			Look Angles to Earth		Look Angles to Moon		Look Angles to Sun	
		IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)
02:49:46	TLI cutoff (inertial attitude hold not simulated)	43.7	2.3	179.4	90.0	0.0	30.3	-3.6	10.0	-45.5
02:50:06	S-IVB maneuver to local horizontal orientation, rolled 180 deg local attitude hold	41.8	2.3	179.5	90.0	0.0	28.4	-3.8	8.4	-54.7
03:05:00	S-IVB maneuver to CSM/S-IVB separation attitude, inertial attitude hold	106.1	40.6	-3.1	131.6	48.2	89.8	177.8	68.2	-170.4
03:15:00	CSM/S-IVB separation	106.1	40.6	-3.1	120.9	30.1	89.9	177.7	68.2	-170.4
03:17:00	CSM null separation rate, pitch 180 deg and roll -60 deg for docking	-73.9	-40.6	-56.9	60.9	-147.9	90.1	62.3	111.8	50.4
03:25:00	CSM/LM docking	-73.9	-40.6	-56.9	66.8	-141.1	90.1	62.3	111.8	50.4
04:09:45	LM ejection	-73.9	-40.6	-56.9	82.2	-125.7	90.3	62.3	111.7	50.4
04:20:00	CSM pitch -75 deg and roll to visually acquire S-IVB	-147.6	-3.1	56.9	9.7	129.0	163.7	-45.8	168.0	71.4
04:39:45	SPS evasive maneuver burn ignition	-147.6	-3.1	56.9	13.8	127.7	163.8	-45.8	168.0	71.4
04:39:48	Evasive maneuver burn cutoff, inertial attitude hold	-147.6	-3.1	56.9	13.8	127.7	163.8	-45.8	168.0	71.4
05:30:00	Begin IMU realignment	← Maneuver spacecraft as required →								
06:00:00	Begin star-earth horizon navigation sightings	← Maneuver spacecraft as required →								
10:40:00	Begin IMU realignment	← Maneuver spacecraft as required →								
11:45:00	SPS midcourse burn ignition	← Maneuver spacecraft as required →								
12:00:00	Begin IMU realignment, change to PTC REFSMMAT	← Maneuver spacecraft as required →								

Table II. Spacecraft Attitude and Trajectory Data
(b) Translunar (Continued)

Mission Time (hr:min:sec)	Event	IMU Gimbal Angles			Look Angles to Earth		Look Angles to Moon		Look Angles to Sun	
		IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)
12:20:00	Begin PTC	-90.0	0.0	0.0	87.9	-8.7	92.8	-164.9	90.0	-144.3
24:10:00	Terminate PTC, begin IMU realignment	← Maneuver spacecraft as required →								
24:30:00	Begin star-earth horizon navigation sightings	← Maneuver spacecraft as required →								
26:45:00	Midcourse correction	← Maneuver spacecraft as required →								
27:00:00	Begin PTC	-90.0	0.0	0.0	89.1	-17.2	93.0	-160.8	90.0	-144.8
53:00:00	Terminate PTC, begin IMU realignment	← Maneuver spacecraft as required →								
53:55:00	Midcourse correction	← Maneuver spacecraft as required →								
54:00:00	Begin PTC	-90.0	0.0	0.0	89.9	-22.7	93.2	-156.0	90.0	-145.9
70:00:00	Terminate PTC, begin IMU realignment to landing site REFSMMAT	← Maneuver spacecraft as required →								
70:55:00	Midcourse correction	← Maneuver spacecraft as required →								
73:32:00	Begin IMU realignment	← Maneuver spacecraft as required →								
74:05:00	Maneuver to LOI-1 burn attitude, inertial attitude hold	-134.6	-13.8	-2.1	90.3	2.4	154.5	-157.1	145.0	-157.6
74:10:00	Roll 60.0 deg for MSFN	-134.6	-13.8	57.8	90.3	-57.6	155.2	142.9	145.0	142.4
74:15:00	Roll -60.0 deg to LOI-1 burn attitude	-134.6	-13.8	-2.1	90.3	2.4	155.9	-155.0	145.0	-157.7
74:25:00	Begin -0.3 deg/sec pitch rate	-134.6	-13.8	-2.1	90.3	2.4	157.4	-154.6	145.0	-157.6
74:45:00	Terminate pitch rate, inertial attitude hold	-134.6	-13.8	-2.1	90.3	2.4	161.5	-148.5	145.0	-157.6
75:45:34	Lose MSFN line of sight	-134.6	-13.8	-2.1	No line of sight					
75:54:28	LOI-1 burn ignition	-134.6	-13.8	-2.1	No line of sight		104.3	-0.2	144.9	-157.7

Table II. Spacecraft Attitude and Trajectory Data
(c) Lunar Orbit
Part 1: LOI-1 Burn Cutoff to CSM/LM Undocking

Mission Time (hr:min:sec)	Event	Selenographic Position			Local Horizontal Attitude			IMU Gimbal Angles			Look Angles to Earth		Look Angles to Sun		Optics Angles to Landmark	
		Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Shaft (deg)	Trunnion (deg)
76:00:27	LOI-1 cutoff, inertial attitude hold	59.8	0.4	164.8	-171.4	-13.4	-2.3	-135.1	-13.4	-2.3	No line of sight		144.6	-158.4		
76:02:00	Maneuver to lunar observation attitude, local attitude hold	61.1	0.5	160.0	-45.0	0.0	180.0	-13.5	0.0	180.0	No line of sight		91.5	-179.8		
76:19:01	Acquire MSFN line of sight	92.9	1.2	108.5	-45.0	0.0	180.0	-64.7	0.0	180.0	19.8	-179.2	142.8	-179.7		
77:02:03	Enter lunar umbra	167.1	-0.2	-6.3	-45.0	0.0	180.0	-179.1	0.0	180.0	134.8	-179.5	No line of sight			
77:43:57	Lose MSFN line of sight	84.4	-1.1	-119.6	-45.0	0.0	180.0	68.0	0.0	180.0	No line of sight		No line of sight			
77:48:10	Enter sunlight	75.1	-0.9	-132.2	-45.0	0.0	180.0	55.4	0.0	180.0	No line of sight		22.7	-179.5		
78:27:08	Acquire MSFN line of sight	91.7	1.2	108.3	-45.0	0.0	180.0	-63.8	0.0	180.0	19.9	-178.9	141.9	-179.7		
79:10:00	Terminate orbital pitch rate, inertial attitude hold	167.2	-0.1	-6.2	-45.0	0.0	180.0	-177.9	0.0	180.0	134.7	-179.4	104.0	-0.2		
79:10:23	Enter lunar umbra	167.1	-0.2	-7.2	-44.0	0.0	180.0	-177.9	0.0	180.0	134.7	-179.4	No line of sight			
79:15:00	Begin IMU realignment	164.8	-0.4	-18.9	-32.3	0.0	180.0	-177.9	0.0	180.0	134.8	-179.4	No line of sight			
79:35:00	Maneuver to LOI-2 burn attitude, inertial attitude hold	129.7	-1.2	-71.3	50.1	-0.4	0.0	-147.7	-0.4	0.0	104.9	0.4	No line of sight			
79:52:09	Lose MSFN line of sight	85.2	-1.1	-120.0	98.6	-0.4	0.0	-147.7	-0.4	0.0	No line of sight		No line of sight			
79:56:32	Enter sunlight	75.5	-0.9	-133.1	111.7	-0.4	0.0	-147.7	-0.4	0.0	No line of sight		134.2	-179.9		
80:09:30	LOI-2 ignition	58.7	-0.2	-173.0	151.5	-0.4	0.0	-147.7	-0.4	0.0	No line of sight		134.2	-179.9		
80:09:46	LOI-2 cutoff, inertial attitude hold	58.7	-0.1	-173.8	152.3	-0.4	0.0	-147.7	-0.4	0.0	No line of sight		134.2	-179.9		
80:15:00	Maneuver to lunar observation attitude, local attitude hold	60.3	0.2	170.3	-45.0	0.0	180.0	-0.8	0.0	180.0	No line of sight		79.0	-179.8		
80:36:57	Acquire MSFN line of sight	63.7	1.2	104.0	-45.0	0.0	180.0	-66.9	0.0	180.0	24.1	-178.8	145.0	-179.7		
81:09:00	Terminate orbital pitch rate, inertial attitude hold	56.7	0.2	7.0	-45.0	0.0	180.0	-163.6	0.0	180.0	121.3	-179.4	118.2	-0.2		
81:09:55	Enter lunar umbra	56.4	0.1	4.2	-42.2	0.0	180.0	-163.6	0.0	180.0	121.3	-179.4	No line of sight			
81:10:00	Begin IMU realignment	56.4	0.1	4.0	-42.0	0.0	180.0	-163.6	0.0	180.0	121.3	-179.4	No line of sight			
81:48:38	Lose MSFN line of sight	53.2	-1.1	-114.9	76.5	0.0	180.0	-163.6	0.0	180.0	No line of sight		No line of sight			
81:55:54	Enter sunlight	55.0	-0.9	-137.2	98.8	0.0	180.0	-163.6	0.0	180.0	No line of sight		118.2	-0.2		
82:26:00	Maneuver to landmark tracking attitude, inertial attitude hold	62.9	0.9	131.4	-63.2	0.0	0.0	-56.6	0.0	0.0	No line of sight		134.9	0.3		
82:35:19	Acquire MSFN line of sight	63.4	1.2	103.3	-35.1	0.0	0.0	-56.6	0.0	0.0	15.0	2.3	134.9	0.3		
82:46:18	Begin -0.3 deg/sec pitch rate for landmark tracking on A-1	62.3	1.2	70.2	-2.1	0.0	0.0	-56.6	0.0	0.0	15.0	2.3	134.9	0.3	22.9	20.7
82:50:27	Terminate pitch rate, roll 82 deg to sleep attitude, inertial attitude hold	61.5	1.1	57.7	-64.0	0.0	81.5	-131.0	0.0	81.5	89.5	-80.9	150.7	98.1	89.2	86.0
83:08:13	Enter lunar umbra	56.4	0.1	3.2	-9.7	0.0	81.5	-131.0	0.0	81.5	89.8	-80.9	No line of sight			
83:46:48	Lose MSFN line of sight	53.4	-1.1	-114.9	108.1	0.0	81.5	-131.0	0.0	81.5	No line of sight		No line of sight			
83:54:26	Enter sunlight	55.1	-0.9	-138.4	131.4	0.0	81.5	-131.0	0.0	81.5	No line of sight		150.7	98.1		
84:33:20	Acquire MSFN line of sight	63.2	1.2	103.7	-111.0	0.0	81.5	-131.0	0.0	81.5	90.4	-80.8	150.6	98.1		
85:00:00	Start crew sleep period	58.4	0.5	23.0	-30.6	0.0	81.5	-131.0	0.0	81.5	90.7	-80.8	150.6	98.1		
85:06:50	Enter lunar umbra	56.4	0.2	2.2	-9.8	0.0	81.5	-131.0	0.0	81.5	90.8	-80.8	No line of sight			
85:45:06	Lose MSFN line of sight	53.5	-1.1	-115.4	107.5	0.0	81.5	-131.0	0.0	81.5	No line of sight		No line of sight			
85:52:49	Enter sunlight	55.3	-0.9	-139.1	131.1	0.0	81.5	-131.0	0.0	81.5	No line of sight		150.6	98.1		

Table II. Spacecraft Attitude and Trajectory Data
(c) Lunar Orbit (Continued)
Part 1: LOI-1 Burn Cutoff of CSM/LM Undocking

Mission Time (hr:min:sec)	Event	Selenographic Position			Local Horizontal Attitude			IMU Gimbal Angles			Look Angles to Earth		Look Angles to Sun		Optics Angles to Landmark	
		Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Shaft (deg)	Trunnion (deg)
86:31:36	Acquire MSFN line of sight	62.9	1.2	103.2	-111.7	0.0	81.5	-131.0	0.0	81.5	91.4	-80.7	150.6	98.1		
87:05:18	Enter lunar umbra	56.4	0.1	1.1	-9.8	0.0	81.5	-131.0	0.0	81.5	91.9	-80.7	No line of sight			
87:43:19	Lose MSFN line of sight	53.7	-1.2	-115.7	106.6	0.0	81.5	-131.0	0.0	81.5	No line of sight		No line of sight			
87:51:23	Enter sunlight	55.5	-0.9	-140.4	131.3	0.0	81.5	-131.0	0.0	81.5	No line of sight		150.5	98.1		
88:29:55	Acquire MSFN line of sight	62.7	1.2	102.7	-112.2	0.0	81.5	-131.0	0.0	81.5	92.4	-80.6	150.5	98.1		
89:03:46	Enter lunar umbra	56.4	0.1	0.1	-9.9	0.0	81.5	-131.0	0.0	81.5	92.9	-80.6	No line of sight			
89:41:24	Lose MSFN line of sight	53.4	-1.2	-115.5	105.3	0.0	81.5	-131.0	0.0	81.5	No line of sight		No line of sight			
89:49:45	Enter sunlight	55.6	-0.9	-141.1	130.9	0.0	81.5	-131.0	0.0	81.5	No line of sight		150.4	98.1		
90:28:07	Acquire MSFN line of sight	62.4	1.2	102.5	-113.1	0.0	81.5	-131.0	0.0	81.5	93.4	-80.5	150.4	98.1		
91:02:13	Enter lunar umbra	56.5	0.1	-0.9	-10.0	0.0	81.5	-131.0	0.0	81.5	94.0	-80.5	No line of sight			
91:39:49	Lose MSFN line of sight	54.1	-1.2	-116.3	105.1	0.0	81.5	-131.0	0.0	81.5	No line of sight		No line of sight			
91:48:19	Enter sunlight	55.8	-0.9	-142.4	131.1	0.0	81.5	-131.0	0.0	81.5	No line of sight		150.3	98.1		
92:26:27	Acquire MSFN line of sight	62.1	1.2	101.9	-113.5	0.0	81.5	-131.0	0.0	81.5	94.5	-80.4	150.3	98.1		
93:00:39	Enter lunar umbra	56.5	0.1	-1.8	-10.1	0.0	81.5	-131.0	0.0	81.5	95.0	-80.4	No line of sight			
93:37:54	Lose MSFN line of sight	54.3	-1.2	-116.2	103.8	0.0	81.5	-131.0	0.0	81.5	No line of sight		No line of sight			
93:46:41	Enter sunlight	55.9	-0.9	-143.1	130.7	0.0	81.5	-131.0	0.0	81.5	No line of sight		150.3	98.1		
94:00:00	Terminate sleep period	58.9	-0.1	176.4	171.2	0.0	81.5	-131.0	0.0	81.5	No line of sight		150.3	98.1		
94:24:01	Acquire MSFN line of sight	61.9	1.2	103.6	-116.3	0.0	81.5	-131.0	0.0	81.5	95.5	-80.3	150.2	98.1		
94:59:08	Enter lunar umbra	56.5	0.1	-2.9	-10.1	0.0	81.5	-131.0	0.0	81.5	96.1	-80.3	No line of sight			
95:00:00	Roll 40 deg for LM S-band steerable antenna check, inertial attitude hold	56.3	0.0	-55.6	-7.5	0.0	121.5	-131.0	0.0	121.5	96.1	-120.3	No line of sight			
95:35:31	Lose MSFN line of sight	54.4	-1.2	-114.6	101.2	0.0	121.5	-131.0	0.0	121.5	No line of sight		No line of sight			
95:45:15	Enter sunlight	56.1	-0.9	-144.4	130.9	0.0	121.5	-131.0	0.0	121.5	No line of sight		150.2	58.1		
95:52:00	LM occupied	57.5	-0.5	-164.9	151.4	0.0	121.5	-131.0	0.0	121.5	No line of sight		150.2	58.1		
96:22:12	Acquire MSFN line of sight	61.6	1.1	103.5	-117.3	0.0	121.5	-131.0	0.0	121.5	96.5	-120.2	150.2	58.1		
96:57:33	Enter lunar umbra	56.6	0.1	-3.8	-10.3	0.0	121.5	-131.0	0.0	121.5	97.1	-120.2	No line of sight			
97:00:00	Begin IMU realignment	56.1	-0.5	-11.3	-2.8	0.0	121.5	-131.0	0.0	121.5	97.2	-120.2	No line of sight			
97:33:55	Lose MSFN line of sight	54.6	-1.2	-115.3	100.9	0.0	121.5	-131.0	0.0	121.5	No line of sight		No line of sight			
97:43:37	Enter sunlight	56.2	-0.9	-145.0	130.5	0.0	121.5	-131.0	0.0	121.5	No line of sight		150.1	58.1		
98:20:34	Acquire MSFN line of sight	61.4	1.1	102.8	-117.6	0.0	121.5	-131.0	0.0	121.5	97.6	-120.1	150.1	58.1		
98:25:00	Maneuver to landmark tracking attitude, inertial attitude hold	61.2	1.2	89.4	-63.1	0.0	0.0	-89.8	0.0	0.0	56.4	1.7	168.7	0.9		
98:45:10	Begin -0.3 deg/sec pitch rate for landmark tracking on 130	58.7	0.8	28.2	-2.1	0.0	0.0	-89.8	0.0	0.0	56.7	1.7	168.7	0.9	16.5	20.6
98:48:10	Begin -0.5 deg/sec pitch rate	58.1	0.6	19.1	-47.0	0.0	0.0	-143.8	0.0	0.0	110.7	1.5	137.3	179.7	170.5	36.8
98:54:55	Terminate pitch rate in undocking attitude, inertial attitude hold	56.8	0.2	-1.2	131.2	0.0	0.0	13.8	0.0	0.0	46.8	178.1	65.1	0.2		
98:56:02	Enter lunar umbra	56.6	0.1	-4.9	134.6	0.0	0.0	13.8	0.0	0.0	46.7	178.0	No line of sight			
99:00:00	Deploy LM landing gear	55.9	-0.2	-17.0	146.6	0.0	0.0	13.8	0.0	0.0	46.6	178.0	No line of sight			
99:32:02	Lose MSFN line of sight	54.8	-1.2	-119.4	-115.4	0.0	0.0	13.8	0.0	0.0	No line of sight		No line of sight			
99:42:12	Enter sunlight	56.3	-0.9	-146.4	-84.4	0.0	0.0	13.8	0.0	0.0	No line of sight		65.1	0.2		
99:46:00	Maneuver AGS calibration attitude, inertial attitude hold	57.0	-0.7	-158.0	-72.8	14.0	0.0	13.8	14.0	0.0	No line of sight		65.8	-6.2		
99:57:00	Maneuver to undocking attitude, inertial attitude hold	59.0	0.0	168.5	-39.4	0.0	0.0	13.8	0.0	0.0	No line of sight		65.1	0.2		

Table II. Spacecraft Attitude and Trajectory Data
(c) Lunar Orbit
Part 2: CSM/LM Undocking to LM Landing

Mission Time (hr:min:sec)	Event	Vehicle	Selenographic Position			Local Horizontal Attitude			IMU Gimbal Angles			Look Angles to Earth		Look Angles to Sun		Look Angles to Other Vehicle	
			Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)
100:15:00	Undocking, inertial attitude hold	CSM	61.0	1.0	114.0	15.0	0.0	0.0	13.8	0.0	0.0	No line of sight		65.1	0.2	0.0	0.0
		LM	61.0	1.0	114.0	-165.0	0.0	-60.0	-166.2	0.0	-60.0	No line of sight		114.9	-120.2	0.0	0.0
100:17:19	LM maneuver to inspection attitude, continue inertial attitude hold except for 360-deg roll (pilot yaw) maneuver	CSM	61.1	1.1	107.0	22.0	0.0	0.0	13.8	0.0	0.0	No line of sight		65.1	0.2	3.3	179.8
		LM	61.1	1.1	107.0	-48.0	0.0	0.0	-56.2	0.0	0.0	No line of sight		135.1	0.2	113.3	180.0
100:18:40	CSM, LM acquire MSFN line of sight	CSM	61.1	1.1	102.9	26.0	0.0	0.0	13.8	0.0	0.0	46.3	177.9	65.1	0.2	6.1	180.0
		LM	61.1	1.1	102.9	-44.0	0.0	162.0	-56.2	0.0	162.0	23.8	-158.3	135.1	-161.8	116.1	18.0
100:20:19	LM begin station keeping, continue inertial attitude hold	CSM	61.1	1.2	97.9	31.0	0.0	0.0	13.8	0.0	0.0	46.2	177.9	65.1	0.2	9.2	180.0
		LM	61.1	1.2	97.9	-39.0	0.0	0.0	-56.2	0.0	0.0	23.8	3.7	135.1	0.2	119.2	180.0
100:39:50	CSM separation burn ignition, inertial attitude hold	CSM	59.2	0.9	38.7	90.0	0.0	0.0	13.8	0.0	0.0	46.0	177.9	65.1	0.2	6.0	180.0
		LM	59.2	0.9	38.7	20.0	0.0	0.0	-56.2	0.0	0.0	24.1	3.7	135.1	0.2	116.0	180.0
100:40:05	CSM separation burn cutoff, inertial attitude hold	CSM	59.1	0.9	38.0	90.7	0.0	0.0	13.8	0.0	0.0	46.0	177.9	65.1	0.2	4.2	180.0
		LM	59.1	0.9	38.0	20.7	0.0	0.0	-56.2	0.0	0.0	24.1	3.7	135.1	0.2	114.2	180.0
100:45:10	CSM maneuver to SXT tracking - VHF ranging attitude; LM maneuver to RR tracking attitude, line-of-sight maintenance	CSM	58.1	0.7	22.5	140.9	0.0	0.0	48.6	0.0	0.0	80.7	178.5	30.4	0.3	35.0	180.0
		LM	58.3	0.7	22.5	15.9	0.0	0.0	-76.4	0.0	0.0	44.4	2.2	155.4	0.4	90.0	180.0
100:54:28	CSM enter lunar umbra	CSM	56.3	0.1	-5.9	164.1	0.0	0.0	43.5	0.0	0.0	75.3	178.4	No line of sight		35.0	180.0
		LM	56.6	0.1	-5.9	39.1	0.0	0.0	-81.5	0.0	0.0	49.7	2.0	160.5	0.5	90.0	180.0
100:54:30	LM enter lunar umbra	CSM	56.3	0.1	-5.9	164.2	0.0	0.0	43.5	0.0	0.0	75.3	178.4	No line of sight		35.0	180.0
		LM	56.6	0.1	-5.9	39.2	0.0	0.0	-81.5	0.0	0.0	49.7	2.0	No line of sight		90.0	180.0
101:00:00	CSM, LM begin IMU realignment, inertial attitude hold	CSM	55.3	-0.3	-22.8	175.1	0.0	0.0	37.6	0.0	0.0	69.3	178.4	No line of sight		35.0	180.0
		LM	55.7	-0.3	-22.7	50.0	0.0	0.0	-87.4	0.0	0.0	55.7	1.8	No line of sight		90.0	180.0
101:30:27	CSM lose MSFN line of sight	CSM	54.8	-1.2	-116.2	-91.8	0.0	0.0	37.6	0.0	0.0	No line of sight		No line of sight		94.4	180.0
		LM	55.0	-1.2	-116.1	143.1	0.0	0.0	-87.4	0.0	0.0	56.2	1.8	No line of sight		149.4	180.0
101:30:30	LM lose MSFN line of sight	CSM	54.8	-1.2	-116.3	-91.7	0.0	0.0	37.6	0.0	0.0	No line of sight		No line of sight		94.6	180.0
		LM	55.0	-1.2	-116.2	143.2	0.0	0.0	-87.4	0.0	0.0	No line of sight		No line of sight		149.6	180.0
101:34:00	LM maneuver to DOI burn attitude, inertial attitude hold	CSM	55.4	-1.1	-127.1	-111.6	0.0	0.0	7.6	0.0	0.0	No line of sight		No line of sight		72.5	180.0
		LM	55.5	-1.1	-127.0	176.2	0.0	0.0	-65.1	0.0	0.0	No line of sight		No line of sight		179.8	-179.8
101:35:21	CSM maneuver to SXT tracking - VHF ranging attitude, line-of-sight maintenance	CSM	55.6	-1.1	-131.2	-147.4	0.0	0.0	-33.0	0.0	0.0	No line of sight		No line of sight		35.0	180.0
		LM	55.7	-1.1	-131.1	-179.6	0.0	0.0	-65.1	0.0	0.0	No line of sight		No line of sight		177.1	0.0
101:38:48	LM DOI burn ignition, inertial attitude hold	CSM	56.2	-0.9	-141.8	-144.8	0.0	0.0	-40.9	0.0	0.0	No line of sight		No line of sight		35.0	180.0
		LM	56.2	-0.9	-141.6	-169.1	0.0	0.0	-65.1	0.0	0.0	No line of sight		No line of sight		169.2	0.0
101:39:16	LM DOI burn cutoff, inertial attitude hold	CSM	56.2	-0.9	-143.2	-143.7	0.0	0.0	-41.2	0.0	0.0	No line of sight		No line of sight		35.0	180.0
		LM	56.2	-0.9	-143.1	-166.3	0.0	0.0	-63.7	0.0	0.0	No line of sight		No line of sight		167.5	0.0
101:40:42	CSM enter sunlight	CSM	56.4	-0.9	-147.5	-137.6	0.0	0.0	-39.4	0.0	0.0	No line of sight		118.4	0.0	35.0	180.0
		LM	56.2	-0.9	-147.3	-162.1	0.0	0.0	-63.7	0.0	0.0	No line of sight		No line of sight		169.4	0.0
101:40:46	LM enters sunlight	CSM	56.4	-0.9	-147.7	-137.1	0.0	0.0	-39.3	0.0	0.0	No line of sight		118.3	0.0	35.0	180.0
		LM	56.2	-0.9	-147.5	-161.9	0.0	0.0	-63.7	0.0	0.0	No line of sight		142.7	0.0	169.4	0.0
101:40:48	LM maneuver to RR tracking attitude	CSM	56.5	-0.8	-147.9	-137.1	0.0	0.0	-39.3	0.0	0.0	No line of sight		118.3	0.0	35.0	180.0
		LM	56.1	-0.8	-147.7	97.8	0.0	0.0	-164.3	0.0	0.0	No line of sight		116.7	180.0	90.0	180.0
101:43:48	LM RR tracking attitude lock-on, line-of-sight maintenance	CSM	57.1	-0.7	-157.0	-126.1	0.0	0.0	-37.4	0.0	0.0	No line of sight		116.4	0.0	35.0	180.0
		LM	55.5	-0.7	-156.8	108.7	0.0	0.0	-162.4	0.0	0.0	No line of sight		118.6	180.0	90.0	180.0
101:45:48	LM terminates tracking, inertial attitude hold	CSM	57.5	-0.6	-163.1	-118.9	0.0	0.0	-36.3	0.0	0.0	No line of sight		115.3	0.0	35.0	180.0
		LM	54.7	-0.6	-162.8	115.8	0.0	0.0	-161.3	0.0	0.0	No line of sight		119.7	180.0	90.0	180.0
101:53:48	LM pitches down to PDI pitch orientation, inertial attitude hold	CSM	59.0	-0.1	172.5	-86.9	0.0	0.0	-28.6	0.0	0.0	No line of sight		105.8	0.0	35.0	180.0
		LM	50.4	-0.1	172.9	47.8	0.0	0.0	106.5	0.0	0.0	No line of sight		27.4	180.0	10.0	0.0
101:58:48	LM 180-deg roll (pilot yaw left) to PDI attitude, inertial attitude hold	CSM	59.9	0.2	157.3	-65.1	0.0	0.0	-21.9	0.0	0.0	No line of sight		101.0	0.0	35.0	180.0
		LM	45.0	0.2	157.5	63.1	0.0	180.0	100.5	0.0	180.0	No line of sight		27.4	0.0	10.0	180.0

Table II. Spacecraft Attitude and Trajectory Data
(c) Lunar Orbit (Continued)
Part 2: CSM/LM Undocking to LM Landing

Mission Time (hr:min:sec)	Event	Vehicle	Selenographic Position			Local Horizontal Attitude			IMU Gimbal Angles			Look Angles to Earth		Look Angles to Sun		Look Angles to Other Vehicle	
			Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)
102:16:30	CSM acquires MSFN line of sight, terminates automatic tracking, inertial attitude hold	CSM	61.2	1.1	103.7	-12.5	0.0	0.0	-22.7	0.0	0.0	8.8	169.6	101.7	0.0	35.0	180.0
		LM	21.8	1.1	101.5	119.0	0.0	180.0	106.5	0.0	180.0	No line of sight		27.4	0.0	15.8	180.0
102:18:30	CSM maneuver to heads-up SXT tracking - VHF ranging attitude, line-of-sight maintenance	CSM	61.2	1.2	97.7	-9.2	0.0	0.0	-25.5	0.0	0.0	6.1	165.0	104.5	0.0	35.0	180.0
		LM	19.4	1.2	94.9	125.5	0.0	180.0	106.5	0.0	180.0	No line of sight		27.4	0.0	13.1	180.0
102:18:35	LM acquire MSFN line of sight	CSM	61.2	1.2	97.5	-9.1	0.0	0.0	-25.3	0.0	0.0	6.0	165.0	104.7	0.0	35.0	180.0
		LM	19.4	1.2	94.7	125.7	0.0	180.0	106.5	0.0	180.0	137.8	0.0	27.4	0.0	13.0	180.0
102:31:14	CSM terminates automatic tracking, inertial attitude hold	CSM	60.1	1.2	59.1	5.5	0.0	0.0	-49.3	0.0	0.0	18.1	0.0	128.3	0.0	35.0	180.0
		LM	9.1	1.1	52.9	167.4	0.0	180.0	106.5	0.0	180.0	137.8	0.0	27.4	0.0	10.7	0.0
102:35:14	LM PDI burn ignition	CSM	59.5	1.1	47.0	17.5	0.0	0.0	-49.3	0.0	0.0	18.1	0.0	128.3	0.0	44.0	180.0
		LM	8.2	1.0	39.6	-179.3	0.0	180.0	106.5	0.0	180.0	137.8	0.0	27.4	0.0	19.7	0.0
102:36:14	CSM begins -0.2 deg/sec pitch rate to insure SXT tracking	CSM	59.4	1.0	44.0	20.5	0.0	0.0	-49.3	0.0	0.0	18.1	0.0	128.3	0.0	51.4	180.0
		LM	8.1	0.9	36.3	177.2	0.0	180.0	99.8	0.0	180.0	130.9	0.0	20.7	0.0	15.5	0.0
102:38:14	LM 180-deg roll (pilot yaw right)	CSM	59.1	0.9	37.9	2.6	0.0	0.0	-73.2	0.0	0.0	42.2	0.0	152.3	0.0	29.9	180.0
		LM	6.5	0.8	30.8	169.5	0.0	0.0	86.6	0.0	0.0	117.6	180.0	7.5	180.0	9.8	180.0
102:47:11	LM landing	CSM	57.4	0.5	10.7	-77.7	0.0	0.0	179.3	0.0	0.0	149.8	0.0	100.2	180.0	80.9	180.0
		LM	0.0	0.7	23.7	90.0	0.0	0.0	0.0	0.0	0.0	32.3	180.0	77.8	0.0	82.9	180.0

Table II. Spacecraft Attitude and Trajectory Data
(c) Lunar Orbit
Part 3: LM Landing to LM Lift-off (CSM Solo Operations)

Mission Time (hr:min:sec)	Event	Selenographic Position			Local Horizontal Attitude			IMU Gimbal Angles			Look Angles to Earth		Look Angles to Sun		Optics Angles to Landmark	
		Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Shaft (deg)	Trunnion (deg)
102:47:12	CSM continue -0.2 deg/sec pitch rate	57.4	0.5	10.7	-77.7	0.0	0.0	179.2	0.0	0.0	149.8	3.2	100.2	179.8		
102:52:56	CSM enter lunar umbra	56.4	0.1	-6.9	-146.6	0.0	0.0	92.8	0.0	0.0	123.6	178.1	No line of sight			
103:00:00	CSM terminate pitch rate; begin IMU realignment, inertial attitude hold	55.2	-0.4	-28.5	-125.1	0.0	0.0	92.8	0.0	0.0	123.4	178.1	No line of sight			
103:28:34	CSM lose MSFN line of sight	55.0	-1.2	-116.1	-37.7	0.0	0.0	92.8	0.0	0.0	No line of sight		No line of sight			
103:39:10	CSM enter sunlight	56.7	-0.9	-148.6	-5.4	0.0	0.0	92.8	0.0	0.0	No line of sight		13.7	179.3		
104:10:00	CSM maneuver to LM tracking attitude local attitude hold	60.9	0.9	117.8	-22.0	0.0	0.0	-17.2	0.0	0.0	No line of sight		96.3	0.2		
104:14:54	CSM acquire MSFN line of sight	61.0	1.1	102.9	-22.0	0.0	0.0	-32.0	0.0	0.0	2.4	45.2	111.1	0.2		
104:46:00	CSM maneuver to plane change attitude, yawed 45 deg, inertial attitude hold	57.3	0.4	8.5	179.9	45.0	-64.2	75.9	45.0	-64.2	99.8	-128.3	44.9	-21.2		
104:51:25	CSM enter lunar umbra	56.4	0.1	-8.0	-163.6	45.0	-64.2	75.9	45.0	-64.2	99.7	-128.2	No line of sight			
105:00:00	CSM begin IMU realignment	55.2	-0.4	-34.2	-137.4	45.0	-64.2	42.2	-17.3	7.7	99.6	-128.1	No line of sight			
105:26:22	CSM lose MSFN line of sight	55.2	-1.2	-115.1	-56.8	45.0	-64.2	42.2	-17.3	7.7	No line of sight		No line of sight			
105:37:36	CSM enter sunlight	56.8	-0.9	-149.5	-22.6	45.0	-64.2	42.2	-17.3	7.7	No line of sight		44.9	-21.1		
106:12:57	CSM acquire MSFN line of sight	60.7	1.1	103.2	84.5	45.0	-64.2	42.2	-17.3	7.7	99.4	-127.9	44.9	-21.1		
106:40:00	CSM maneuver to plane change attitude, inertial attitude hold	58.0	0.7	21.1	166.3	86.8	-64.2	2.9	-1.3	1.1	89.0	-130.7	86.6	-22.5		
106:49:51	CSM enter lunar umbra	56.5	0.1	-8.9	-163.7	86.8	-64.2	2.9	-1.3	1.1	89.0	-130.5	No line of sight			
107:05:33	CSM plane change burn	54.8	-0.8	-57.0	-115.8	86.8	-64.2	2.9	-1.3	1.1	89.0	-130.1	No line of sight			
107:10:00	CSM maneuver to IMU realignment attitude, inertial attitude hold	54.7	-1.0	-70.6	-102.1	45.1	-64.4	42.2	-17.3	7.7	98.6	-127.2	No line of sight			
107:15:00	CSM begin IMU realignment	54.7	-1.1	-85.9	-86.8	45.1	-64.4	64.2	45.1	-64.4	98.6	-127.2	No line of sight			
107:24:41	CSM lose MSFN line of sight	55.4	-1.1	-115.6	-57.2	45.1	-64.4	64.2	45.1	-64.4	98.5	-127.1	No line of sight			
107:35:00	CSM maneuver to sleep attitude, inertial attitude hold	56.7	-0.7	-14.7	127.7	0.0	81.5	-142.4	0.0	81.5	No line of sight		No line of sight			
107:36:12	CSM enter sunlight	56.9	-0.7	-150.8	131.4	0.0	81.5	-142.4	0.0	81.5	No line of sight		150.3	98.0		
108:11:11	CSM acquire MSFN line of sight	60.5	1.0	102.9	-122.6	0.0	81.5	-142.4	0.0	81.5	102.3	-79.5	150.2	98.0		
108:48:12	CSM enter lunar umbra	56.5	0.0	-9.6	-10.5	0.0	81.5	-142.4	0.0	81.5	102.9	-79.4	No line of sight			
109:23:00	CSM lose MSFN line of sight	55.6	-1.1	-116.2	95.8	0.0	81.5	-142.4	0.0	81.5	No line of sight		No line of sight			
109:34:34	CSM enter sunlight	57.0	-0.7	-151.5	131.0	0.0	81.5	-142.4	0.0	81.5	No line of sight		150.2	98.0		
110:09:28	CSM acquire MSFN line of sight	60.2	1.0	102.5	-123.3	0.0	81.5	-142.4	0.0	81.5	103.3	-79.3	150.2	98.0		
110:46:48	CSM enter lunar umbra	56.6	0.0	-11.0	-10.1	0.0	81.5	-142.4	0.0	81.5	103.9	-79.3	No line of sight			
111:21:16	CSM lose MSFN line of sight	55.8	-1.1	-116.5	95.0	0.0	81.5	-142.4	0.0	81.5	No line of sight		No line of sight			
111:33:08	CSM enter sunlight	57.2	-0.7	-152.8	131.2	0.0	81.5	-142.4	0.0	81.5	No line of sight		150.1	98.0		
112:07:43	CSM acquire MSFN line of sight	60.0	1.0	102.1	-124.0	0.0	81.5	-142.4	0.0	81.5	104.4	-79.2	150.1	98.0		
112:45:08	CSM enter lunar umbra	56.6	0.0	-11.7	-10.6	0.0	81.5	-142.4	0.0	81.5	105.0	-79.2	No line of sight			
113:19:16	CSM lose MSFN line of sight	56.0	-1.1	-116.1	93.5	0.0	81.5	-142.4	0.0	81.5	No line of sight		No line of sight			
113:20:00	CSM maneuver to lunar surface observation attitude, local attitude hold	56.1	-1.1	-118.3	-78.0	0.0	180.0	43.9	0.0	180.0	No line of sight		No line of sight			
113:31:31	CSM enter sunlight	57.3	-0.7	-153.5	-78.0	0.0	180.0	8.8	0.0	180.0	No line of sight		58.8	-179.7		
114:05:54	CSM acquire MSFN line of sight	59.7	1.0	102.0	-78.0	0.0	180.0	-95.4	0.0	180.0	58.5	-177.3	163.0	-179.2		

Table II. Spacecraft Attitude and Trajectory Data
(c) Lunar Orbit (Continued)
Part 3: LM Landing to LM Lift-off (CSM Solo Operations)

Mission Time (hr:min:sec)	Event	Selenographic Position			Local Horizontal Attitude			IMU Gimbal Angles			Look Angles to Earth		Look Angles to Sun		Optics Angles to Landmark	
		Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Shaft (deg)	Trunnion (deg)
114:20:09	CSM maneuver to inital COAS tracking attitude, local attitude hold	59.0	1.0	58.7	-40.0	0.0	0.0	-100.5	0.0	0.0	63.7	2.6	168.2	1.1		
114:30:09	CSM COAS tracking of LM	58.1	0.7	28.3	-40.3	0.5	-0.6	-131.2	0.5	-0.6	94.6	3.0	161.1	178.4	0.1	58.0
114:32:09	CSM maneuver to lunar surface observation attitude, local attitude hold	57.9	0.6	22.2	-78.0	0.0	180.0	-174.9	0.0	180.0	138.3	-176.5	117.4	-0.3		
114:43:43	CSM enter lunar umbra	56.7	0.0	-130.4	-78.0	0.0	180.0	149.9	0.0	180.0	173.3	-159.4	No line of sight			
115:17:41	CSM lose MSFN line of sight	56.3	-1.1	-116.9	-78.0	0.0	180.0	46.4	0.0	180.0	No line of sight		No line of sight			
115:30:04	CSM enter sunlight	57.4	-0.7	-154.7	-78.0	0.0	180.0	8.7	0.0	180.0	No line of sight		59.0	-179.7		
116:04:17	CSM acquire MSFN line of sight	59.5	1.0	101.2	-78.0	0.0	180.0	-95.0	0.0	180.0	59.2	-177.2	162.8	-179.2		
116:30:00	CSM maneuver to sleep attitude, inertial atttiude hold	57.8	0.6	23.1	-47.4	0.0	81.5	-142.4	0.0	81.5	106.8	-79.0	149.9	98.0		
116:42:04	CSM enter lunar umbra	56.8	0.0	-13.7	-10.7	0.0	81.5	-142.4	0.0	81.5	107.1	-79.0	No line of sight			
117:15:49	CSM lose MSFN line of sight	56.5	-1.1	-116.9	92.2	0.0	81.5	-142.4	0.0	81.5	No line of sight		No line of sight			
117:28:27	CSM enter sunlight	57.5	-0.7	-155.4	130.6	0.0	81.5	-142.4	0.0	81.5	No line of sight		149.9	98.0		
118:02:23	CSM acquire MSFN line of sight	59.2	1.0	101.4	-126.5	0.0	81.5	-142.4	0.0	81.5	107.5	-78.9	149.9	98.0		
118:40:38	CSM enter lunar umbra	56.8	0.0	-15.1	-10.4	0.0	81.5	-142.4	0.0	81.5	108.2	-78.8	No line of sight			
119:14:05	CSM lose MSFN line of sight	56.7	-1.1	-117.3	91.5	0.0	81.5	-142.4	0.0	81.5	No line of sight		No line of sight			
119:27:00	CSM enter sunlight	57.6	-0.7	-156.7	130.7	0.0	81.5	-142.4	0.0	81.5	No line of sight		149.8	98.0		
120:00:02	CSM acquire MSFN line of sight	59.0	1.0	102.8	-129.1	0.0	81.5	-142.4	0.0	81.5	108.6	-78.8	149.8	98.0		
120:39:00	CSM enter lunar umbra	56.9	0.0	-15.8	-10.8	0.0	81.5	-142.4	0.0	81.5	109.2	-78.7	No line of sight			
121:11:45	CSM lose MSFN line of sight	56.9	-1.1	-115.8	88.9	0.0	81.5	-142.4	0.0	81.5	No line of sight		No line of sight			
121:25:24	CSM enter sunlight	57.7	-0.7	-157.5	130.4	0.0	81.5	-142.4	0.0	81.5	No line of sight		149.7	98.0		
121:58:19	CSM acquire MSFN line of sight	58.7	1.0	102.4	-129.7	0.0	81.5	-142.4	0.0	81.5	109.6	-78.7	149.7	98.0		
122:37:33	CSM enter lunar umbra	57.0	0.0	-17.1	-10.6	0.0	81.5	-142.4	0.0	81.5	110.3	-78.6	No line of sight			
123:09:51	CSM lose MSFN line of sight	57.1	-1.1	-115.7	87.7	0.0	81.5	-142.4	0.0	81.5	No line of sight		No line of sight			
123:23:56	CSM enter sunlight	57.8	-0.7	-158.6	130.5	0.0	81.5	-142.4	0.0	81.5	No line of sight		149.6	98.0		
123:56:29	CSM acquire MSFN line of sight	58.4	1.0	102.3	-130.7	0.0	81.5	-142.4	0.0	81.5	110.7	-78.6	149.6	98.0		
124:03:00	CSM maneuver to support LM liftoff, inertial attitude hold	58.3	1.1	82.5	-121.8	0.0	0.0	-153.2	0.0	0.0	121.6	3.3	138.7	179.7		

Table II. Spacecraft Attitude and Trajectory Data
(c) Lunar Orbit
Part 4: LM Lift-off to CSM/LM Docking

Mission Time (hr:min:sec)	Event	Vehicle	Selenographic Position			Local Horizontal Attitude			IMU Gimbal Angles			Look Angles to Earth		Look Angles to Sun		Look Angles to Other Vehicle	
			Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)
124:23:21	LM lift-off, CSM initiates -0.2 deg/sec pitch rate for RR tracking	CSM	57.5	0.7	20.5	-60.0	0.0	0.0	-153.2	0.0	0.0	121.9	0.0	138.7	180.0	71.2	180.0
		LM	0.0	0.7	23.7	90.0	0.0	0.0	0.0	0.0	0.0	32.7	180.0	66.8	0.0	45.7	180.0
124:30:44	Insertion burn cutoff, inertial attitude hold	CSM	57.2	0.3	-1.8	-125.4	0.0	0.0	119.2	0.0	0.0	150.1	174.3	51.1	180.0	36.4	180.0
		LM	9.9	0.6	13.5	-2.4	0.0	0.0	-102.6	0.0	0.0	71.5	0.0	170.7	0.0	5.4	0.0
124:35:44	CSM and LM begin IMU realignment	CSM	57.1	0.0	-17.3	180.0	0.0	0.0	49.1	0.0	0.0	80.1	177.1	18.9	0.7	18.0	0.0
		LM	10.4	0.3	-3.1	90.0	0.0	0.0	-26.7	0.0	0.0	5.2	147.1	94.7	0.2	86.2	180.0
124:35:58	CSM enter lunar umbra	CSM	57.1	0.0	-17.5	-179.2	0.0	0.0	49.1	0.0	0.0	80.1	177.1	No line of sight		16.0	0.0
124:36:49	LM enter lunar umbra	LM	11.2	0.2	-7.3	-176.7	0.0	0.0	-26.7	0.0	0.0	5.2	147.1	No line of sight		91.0	180.0
124:40:44	CSM completes IMU realignment, begins VHF ranging	CSM	57.0	-0.3	-32.5	-127.5	0.0	0.0	86.4	0.0	0.0	117.2	176.8	No line of sight		35.0	180.0
		LM	13.9	0.0	-19.5	106.4	0.0	0.0	-26.7	0.0	0.0	5.1	146.3	No line of sight		101.9	180.0
124:55:44	LM completes IMU realignment, begins RR tracking	CSM	57.0	-1.0	-78.3	-130.6	0.0	0.0	37.7	0.0	0.0	68.3	177.0	No line of sight		35.0	180.0
		LM	28.1	-0.9	-68.0	94.1	0.0	0.0	-87.3	0.0	0.0	56.7	3.4	No line of sight		90.0	180.0
125:08:13	CSM lose MSFN line of sight	CSM	57.3	-1.1	-116.4	-133.6	0.0	0.0	-1.9	0.0	0.0	No line of sight		No line of sight		35.0	180.0
125:10:06	LM lose MSFN line of sight	LM	40.1	-1.1	-113.1	91.8	0.0	0.0	-136.6	0.0	0.0	No line of sight		No line of sight		90.0	180.0
125:11:19	CSM and LM terminate VHF ranging and RR tracking, respectively; CSM maneuver to MI CSI burn attitude, inertial attitude hold; LM continue line-of-sight maintenance of CSM along LM Z-axis	CSM	57.4	-1.0	-125.8	150.0	0.0	0.0	-89.1	0.0	0.0	No line of sight		No line of sight		40.6	0.0
		LM	40.8	-1.1	-116.9	91.7	0.0	0.0	-138.5	0.0	0.0	No line of sight		No line of sight		90.0	180.0
125:21:19	CSI burn ignition	CSM	57.8	-0.7	-156.3	180.0	0.0	0.0	-89.1	0.0	0.0	No line of sight		No line of sight		9.4	0.0
		LM	43.6	-0.8	-147.8	88.8	0.0	0.0	-172.2	0.0	0.0	No line of sight		No line of sight		87.5	180.0
125:22:04	CSI burn cutoff, LM continue line-of-sight maintenance of CSM along LM Z-axis	CSM	57.8	-0.7	-158.6	-177.7	0.0	0.0	-89.1	0.0	0.0	No line of sight		No line of sight		7.1	0.0
		LM	43.6	-0.8	-150.1	91.2	0.0	0.0	-172.2	0.0	0.0	No line of sight		No line of sight		89.8	180.0
125:22:24	CSM enter sunlight	CSM	57.9	-0.7	-159.6	-176.6	0.0	0.0	-89.1	0.0	0.0	No line of sight		157.2	0.4	5.8	0.0
125:25:50	LM enter sunlight	LM	43.6	-0.6	-161.8	91.6	0.0	0.0	179.0	0.0	0.0	No line of sight		110.9	180.0	90.0	180.0
125:28:04	CSM and LM begin VHF ranging and RR tracking, respectively	CSM	58.0	-0.4	-176.9	-135.0	0.0	0.0	-65.0	0.0	0.0	No line of sight		133.1	0.3	35.0	180.0
		LM	43.5	-0.5	-168.8	91.9	0.0	0.0	170.0	0.0	0.0	No line of sight		101.9	179.8	90.0	180.0
125:54:45	CSM acquire MSFN line of sight	CSM	58.2	1.0	101.9	-133.7	0.0	0.0	-145.6	0.0	0.0	115.0	3.1	146.3	179.6	35.0	180.0
125:57:41	LM acquire MSFN line of sight	LM	42.7	1.0	99.0	95.6	0.0	0.0	80.5	0.0	0.0	111.0	176.9	12.4	178.9	90.0	180.0
126:07:37	CSM and LM terminate VHF ranging and RR tracking, respectively; CSM roll 180 deg from VHF ranging attitude for HGA communications, inertial attitude hold; LM maneuver to CDH burn attitude, inertial attitude hold	CSM	57.8	1.1	62.7	-132.7	0.0	180.0	177.2	0.0	180.0	152.2	-173.8	109.1	-0.2	35.0	0.0
		LM	42.5	1.1	68.0	37.6	0.0	0.0	-7.2	0.0	0.0	23.4	172.7	75.3	0.2	30.5	180.0
126:19:37	CDH burn ignition	CSM	57.5	0.8	26.2	-96.3	0.0	180.0	177.2	0.0	180.0	152.4	-173.7	109.1	-0.2	70.3	0.0
		LM	42.5	0.8	30.5	74.9	0.0	0.0	-7.2	0.0	0.0	23.2	172.7	75.3	0.2	65.9	180.0
126:19:39	CDH burn cutoff; inertial attitude hold	CSM	57.5	0.8	26.1	-96.2	0.0	180.0	177.2	0.0	180.0	152.4	-173.7	109.1	-0.2	70.4	0.0
		LM	42.5	0.8	30.4	74.9	0.0	0.0	-7.2	0.0	0.0	23.2	172.7	75.3	0.2	65.9	180.0
126:23:39	CSM and LM begin VHF ranging and RR tracking, respectively	CSM	57.4	0.6	13.9	-131.0	0.0	0.0	130.3	0.0	0.0	160.2	171.4	62.1	179.7	35.0	180.0
		LM	42.4	0.6	18.0	99.9	0.0	0.0	5.3	0.0	0.0	35.5	175.0	62.9	0.3	90.0	180.0
126:34:28	CSM enter lunar umbra	CSM	57.2	0.0	-19.1	-128.5	0.0	0.0	96.3	0.0	0.0	126.1	176.4	No line of sight		35.0	180.0
126:34:42	LM enter lunar umbra	LM	42.2	0.0	-16.5	103.3	0.0	0.0	-28.7	0.0	0.0	3.1	112.0	No line of sight		90.0	180.0
126:42:39	CSM and LM terminate VHF ranging and RR tracking, respectively; CSM maneuver to MI TPI burn attitude, inertial attitude hold; LM continue line-of-sight maintenance of CSM along LM Z-axis	CSM	57.1	-0.5	-44.1	161.3	0.0	0.0	8.8	0.0	0.0	34.6	175.1	No line of sight		33.5	0.0
		LM	42.2	-0.4	-41.3	106.0	0.0	0.0	-47.7	0.0	0.0	18.3	9.3	No line of sight		90.0	180.0

Table II. Spacecraft Attitude and Trajectory Data
(c) Lunar Orbit (Continued)
Part 4: LM Lift-off to CSM/LM Docking

Mission Time (hr:min:sec)	Event	Vehicle	Selenographic Position			Local Horizontal Attitude			IMU Gimbal Angles			Look Angles to Earth		Look Angles to Sun		Look Angles to Other Vehicle	
			Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)
126:58:08	TPI burn ignition	CSM	57.3	-1.1	-92.2	-151.7	0.0	0.0	8.8	0.0	0.0	34.7	175.2	No line of sight		0.0	0.0
		LM	42.4	-1.1	-90.6	116.4	0.0	0.0	-86.5	0.0	0.0	57.1	3.2	No line of sight		90.0	180.0
126:58:30	TPI burn cutoff, CSM and LM begin SXT tracking - VHF ranging and RR tracking, respectively	CSM	57.4	-1.1	-93.4	-150.4	0.0	0.0	8.8	0.0	0.0	34.7	175.2	No line of sight		1.0	180.0
		LM	42.4	-1.1	-91.8	118.6	0.1	0.2	-85.4	0.1	0.2	56.0	3.2	No line of sight		91.6	180.0
127:05:58	LM lose MSFN line of sight	LM	44.0	-1.1	-114.1	123.9	0.0	0.0	-98.8	0.0	0.0	No line of sight		No line of sight		90.0	180.0
127:06:25	CSM lose MSFN line of sight	CSM	57.6	-1.1	-116.6	-106.1	0.0	0.0	20.9	0.0	0.0	No line of sight		No line of sight		35.0	180.0
127:20:47	CSM enter sunlight	CSM	57.9	-0.7	-159.8	-84.5	0.0	0.0	6.1	0.0	0.0	No line of sight		62.1	0.3	35.0	180.0
127:21:18	LM enter sunlight	LM	50.3	-0.7	-161.7	157.9	0.0	0.0	-120.6	0.0	0.0	No line of sight		171.2	178.5	90.0	180.0
127:39:24	First LM braking burn ignition (CSM-LM range = 3000 ft)	CSM	58.1	0.4	142.0	-23.1	-0.5	-0.2	7.0	-0.5	-0.2	No line of sight		61.2	0.8	35.0	180.0
		LM	57.7	0.4	142.0	-150.1	0.0	0.0	-120.1	0.0	0.0	No line of sight		171.7	178.0	88.0	180.0
127:39:35	Braking burn cutoff, CSM maneuver to point X-axis along CSM to LM line of sight, begin line-of-sight maintenance; LM continue Z-axis line-of-sight maintenance	CSM	58.1	0.4	141.4	-22.6	-0.5	-0.3	7.0	-0.5	-0.3	No line of sight		61.2	0.8	35.0	180.0
		LM	57.7	0.4	141.4	-149.4	0.0	0.0	-119.9	0.0	0.0	No line of sight		171.9	177.9	88.0	180.0
127:40:37	Second LM braking burn ignition (CSM-LM range = 1500 ft)	CSM	58.1	0.4	138.3	-52.3	-0.3	-0.5	-25.9	-0.3	-0.5	No line of sight		94.1	0.6	0.0	0.0
		LM	57.9	0.4	138.3	-143.0	0.4	-0.3	-116.7	0.4	-0.3	No line of sight		175.1	172.9	90.0	180.0
127:40:46	Braking burn cutoff, CSM and LM continue line-of-sight maintenance	CSM	58.1	0.4	137.8	-51.8	-0.3	-0.4	-25.9	-0.3	-0.4	No line of sight		94.1	0.6	0.0	0.0
		LM	57.9	0.4	137.8	-142.4	0.4	-0.3	-116.5	0.4	-0.3	No line of sight		175.3	172.6	90.0	180.0
127:42:16	Third LM braking burn ignition (CSM-LM range = 500 ft)	CSM	58.1	0.5	133.3	-47.1	-0.3	-0.4	-25.7	-0.3	-0.4	No line of sight		93.9	0.6	0.0	0.0
		LM	58.0	0.5	133.3	-138.1	0.4	-0.3	-116.8	0.4	-0.3	No line of sight		175.0	173.6	90.0	180.0
127:42:20	Braking burn cutoff, CSM and LM continued line-of-sight maintenance	CSM	58.1	0.5	133.1	-46.9	-0.3	-0.4	-25.7	-0.3	-0.4	No line of sight		93.9	0.6	0.0	0.0
		LM	58.0	0.5	133.1	-137.7	0.4	-0.3	-116.6	0.4	-0.3	No line of sight		175.2	173.3	90.0	180.0
127:43:35	Fourth LM braking burn ignition (CSM-LM range = 100 ft)	CSM	58.1	0.6	129.2	-42.6	-0.3	-0.3	-25.3	-0.3	-0.3	No line of sight		93.5	0.5	0.0	0.0
		LM	58.0	0.6	129.2	-133.3	0.3	-0.3	-116.2	0.3	-0.3	No line of sight		175.6	173.8	90.0	180.0
127:43:39	Braking burn cutoff (CSM-LM range = 90 ft, range rate = -0.2 ft/sec), CSM and LM continue line-of-sight maintenance	CSM	58.1	0.6	129.0	-42.4	-0.3	-0.3	-25.3	-0.3	-0.3	No line of sight		93.5	0.5	0.0	0.0
		LM	58.0	0.6	129.0	-133.2	0.3	-0.3	-116.0	0.3	-0.3	No line of sight		175.8	173.6	90.0	180.0
127:47:00	CSM and LM maneuver to docking attitude (CSM-LM range = 50 ft), being station keeping	CSM	58.0	0.7	119.9	-36.0	0.0	-60.0	-28.0	0.0	-60.0	No line of sight		96.2	60.2	0.0	0.0
		LM	58.0	0.7	119.9	144.0	0.0	0.0	152.0	0.0	0.0	No line of sight		83.8	179.8	0.0	0.0
127:52:44	CSM and LM acquire MSFN line of sight	CSM	57.9	0.9	101.6	-17.8	0.0	-60.0	-28.0	0.0	-60.0	3.3	176.6	96.2	60.2	0.0	0.0
		LM	57.9	0.9	101.6	162.2	0.0	0.0	152.0	0.0	0.0	176.7	63.4	83.8	179.8	0.0	0.0
128:00:00	CSM/LM docking (CSM active) inertial attitude hold	CSM	57.7	1.1	80.3	3.5	0.0	-60.0	-28.0	0.0	-60.0	3.3	175.7	96.2	60.2	0.0	0.0
		LM	57.7	1.1	80.3	-176.5	0.0	0.0	152.0	0.0	0.0	176.7	64.3	83.8	179.8	0.0	0.0

Table II. Spacecraft Attitude and Trajectory Data
(c) Lunar Orbit
Part 5: CSM/LM Docking to TEI

Mission Time (hr:min:sec)	Event	Selenographic Position			Local Horizontal Attitude			IMU Gimbal Angles			Look Angles to Earth		Look Angles to Sun		Optics Angles to Landmark	
		Altitude (n mi)	Latitude (deg)	Longitude (deg)	Pitch (deg)	Yaw (deg)	Roll (deg)	IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Shaft (deg)	Trunnion (deg)
128:00:01	CSM/LM docked, inertial attitude hold	57.7	1.1	80.3	3.5	0.0	-60.0	-28.0	0.0	-60.0	3.3	175.7	96.2	-60.2		
128:06:00	Maneuver to LM jettison attitude, inertial attitude hold	57.6	1.1	62.0	30.0	0.0	0.0	-19.7	0.0	0.0	10.1	162.8	87.9	0.2		
128:32:52	Enter lunar umbra	57.2	0.0	-20.0	111.7	0.0	0.0	-19.7	0.0	0.0	9.6	161.7	87.9	0.2		
129:04:37	Lose MSFN line of sight	57.8	-1.1	-116.7	-151.9	0.0	0.0	-19.7	0.0	0.0	9.2	160.7	87.9	0.2		
129:19:17	Enter sunlight	58.0	-0.7	-161.4	-107.3	0.0	0.0	-19.7	0.0	0.0	9.2	160.7	88.0	0.2		
129:50:55	Acquire MSFN line of sight	57.7	0.9	102.2	-11.2	0.0	0.0	-19.7	0.0	0.0	9.2	160.7	88.0	0.2		
130:31:24	Enter lunar umbra	57.3	0.0	-21.2	111.8	0.0	0.0	-19.7	0.0	0.0	8.6	158.8	88.0	0.2		
131:02:40	Lose MSFN line of sight	58.0	-1.1	-116.5	-153.2	0.0	0.0	-19.7	0.0	0.0	8.2	157.6	88.0	0.2		
131:17:47	Enter sunlight	58.1	-0.7	-162.5	-107.3	0.0	0.0	-19.7	0.0	0.0	8.2	157.6	88.0	0.2		
131:49:08	Acquire MSFN line of sight	57.4	0.9	102.0	-12.1	0.0	0.0	-19.7	0.0	0.0	8.2	157.5	88.0	0.2		
131:53:05	LM jettison	57.3	1.0	90.0	-0.1	0.0	0.0	-19.7	0.0	0.0	8.2	157.5	88.0	0.2		
132:00:00	Maneuver to TEI attitude rolled 180 deg, inertial attitude hold	57.2	1.1	68.9	93.2	13.8	1.1	52.6	13.8	1.1	79.3	178.3	20.7	-40.8		
132:29:43	Enter lunar umbra	56.9	0.0	-21.8	-176.4	13.8	1.1	52.6	13.8	1.1	78.7	178.4	20.7	-40.7		
133:00:44	Lose MSFN line of sight	57.5	-1.1	-116.3	-82.1	13.8	1.1	52.6	13.8	1.1	78.4	178.4	20.7	-40.7		
133:16:12	Enter sunlight	57.7	-0.7	-163.5	-35.1	13.8	1.1	52.6	13.8	1.1	78.4	178.4	20.7	-40.7		
133:47:05	Acquire MSFN line of sight	57.1	0.9	102.4	58.7	13.8	1.1	52.6	13.8	1.1	78.4	178.4	20.7	-40.6		
134:28:14	Enter lunar umbra	57.0	0.0	-23.2	-176.1	13.8	1.1	52.6	13.8	1.1	77.7	178.5	20.8	-40.6		
134:34:00	Begin IMU realignment	57.2	-0.4	-40.7	-158.6	13.8	1.1	52.6	13.8	1.1	77.5	178.6	20.8	-40.6		
134:59:02	Lose MSFN line of sight	57.8	-1.1	-117.0	-82.5	13.8	1.1	52.6	13.8	1.1	77.2	178.6	20.8	-40.5		
135:00:00	Maneuver to TEI burn attitude, inertial attitude hold	57.8	-1.1	-120.0	-79.6	13.8	-178.9	52.6	13.8	-178.9	77.2	-1.3	20.8	139.5		
135:14:41	Enter sunlight	57.8	-0.7	-164.8	-34.9	13.8	-178.9	52.6	13.8	-178.9	77.2	-1.4	20.8	139.5		
135:24:34	TEI burn ignition	57.6	-0.1	165.2	-5.0	13.8	-178.9	52.6	13.8	-178.9	77.3	-1.4	20.8	139.5		

Table II. Spacecraft Attitude and Trajectory Data
(d) Transearth

Mission Time (hr:min:sec)	Event	IMU Gimbal Angles			Look Angles to Earth		Look Angles to Moon		Look Angles to Sun	
		IGA (deg)	MGA (deg)	OGA (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)	Theta (deg)	Phi (deg)
135:27:03	TEI cutoff, maneuver to lunar surface observation attitude, inertial attitude hold	-42.2	-0.5	-175.3	17.4	-172.2	0.0	178.6	110.6	175.4
135:35:21	Acquire MSFN line of sight	-42.2	-0.5	-175.3	17.3	-172.1	35.4	0.0	110.7	175.4
135:40:00	Begin IMU realignment, change to PTC REFSMMAT	← Maneuver spacecraft as required →								
136:00:00	Begin PTC at roll rate of 0.3 deg/sec	-90.0	0.0	0.0	92.8	-55.2	85.6	41.5	90.0	-149.1
149:20:00	Terminate PTC, align IMU	← Maneuver spacecraft as required →								
150:25:00	Perform MCC-5	← Maneuver spacecraft as required →								
150:30:00	Resume PTC	-90.0	0.0	0.0	93.2	-56.2	86.7	81.6	90.0	-149.8
171:05:00	Terminate PTC, align IMU	← Maneuver spacecraft as required →								
172:00:00	Perform MCC-6	← Maneuver spacecraft as required →								
172:10:00	Resume PTC	-90.0	0.0	0.0	94.5	-60.6	86.7	85.4	90.0	-150.5
191:00:00	Terminate PTC, align IMU to entry REFSMMAT	← Maneuver spacecraft as required →								
192:00:00	Perform MCC-7	← Maneuver spacecraft as required →								
193:10:00	Maneuver to entry attitude	156.0	0.0	0.0	126.1	180.0	57.1	-8.9	162.7	66.0
193:35:00	Align IMU	← Maneuver spacecraft as required →								
194:40:00	Maneuver to separation attitude	-70.8	-45.0	0.0	69.5	22.0	75.2	175.1	70.6	49.5
194:50:00	CM/SM separation	-88.2	-45.0	0.0	69.5	22.0	53.8	148.5	89.0	23.7
194:55:00	Maneuver to entry attitude	156.0	0.0	0.0	160.9	0.0	57.0	-8.3	162.7	65.8
195:05:03	Entry interface	156.0	0.0	0.0	114.0	0.0	56.5	-8.2	162.7	65.8

Table III. Mission G IMU Matrices; Launch Date July 16, 1969; 72-Degree Launch Azimuth

Launch Pad

$$\begin{bmatrix}\bar{X}\\ \bar{Y}\\ \bar{Z}\end{bmatrix}_{ECI} = \begin{bmatrix} X_{IMU} & Y_{IMU} & Z_{IMU} \\ -0.87548513 & -0.00736495 & -0.48318894 \\ 0.39990946 & 0.55028486 & -0.73297954 \\ 0.27128992 & -0.83494450 & -0.47882090 \end{bmatrix}$$

PTC

$$\begin{bmatrix}\bar{X}\\ \bar{Y}\\ \bar{Z}\end{bmatrix}_{ECI} = \begin{bmatrix} X_{IMU} & Y_{IMU} & Z_{IMU} \\ 0.86602540 & -0.5 & 0.0 \\ -0.45872739 & -0.79453916 & 0.39784004 \\ -0.19892002 & -0.34453558 & -0.91745480 \end{bmatrix}$$

Landing Site

$$\begin{bmatrix}\bar{X}\\ \bar{Y}\\ Z\end{bmatrix}_{ECI} = \begin{bmatrix} X_{IMU} & Y_{IMU} & Z_{IMU} \\ 0.78005170 & 0.00374214 & 0.62570389 \\ 0.57655390 & -0.39283134 & -0.71642806 \\ 0.24311512 & 0.91960294 & -0.30858630 \end{bmatrix}$$

Plane Change

$$\begin{bmatrix}\bar{X}\\ \bar{Y}\\ Z\end{bmatrix}_{ECI} = \begin{bmatrix} X_{IMU} & Y_{IMU} & Z_{IMU} \\ 0.00350127 & -0.63758434 & 0.77037261 \\ -0.39313783 & -0.70922305 & -0.58518828 \\ 0.91947288 & -0.30081372 & -0.25314170 \end{bmatrix}$$

Lift-off

$$\begin{bmatrix}\bar{X}\\ \bar{Y}\\ Z\end{bmatrix}_{ECI} = \begin{bmatrix} X_{IMU} & Y_{IMU} & Z_{IMU} \\ 0.63482498 & 0.00595991 & 0.77263296 \\ 0.71274769 & -0.39058749 & -0.58260803 \\ 0.29830849 & 0.92054649 & -0.25220262 \end{bmatrix}$$

Entry

$$\begin{bmatrix}\bar{X}\\ \bar{Y}\\ \bar{Z}\end{bmatrix}_{ECI} = \begin{bmatrix} X_{IMU} & Y_{IMU} & Z_{IMU} \\ -0.00422305 & -0.07311520 & -0.99731456 \\ 0.77250890 & 0.63305733 & -0.04968342 \\ 0.63498990 & -0.77064428 & 0.05380744 \end{bmatrix}$$

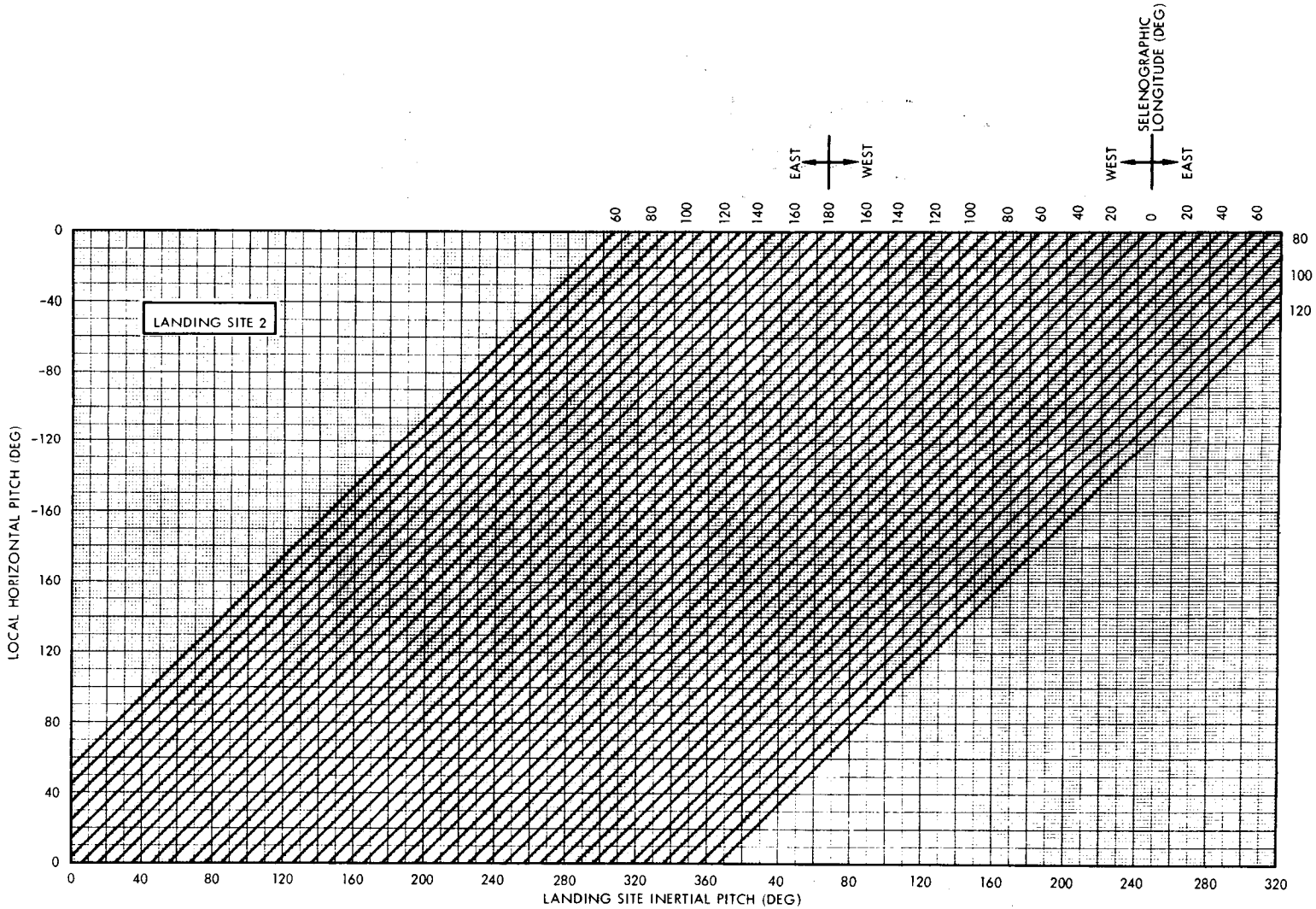
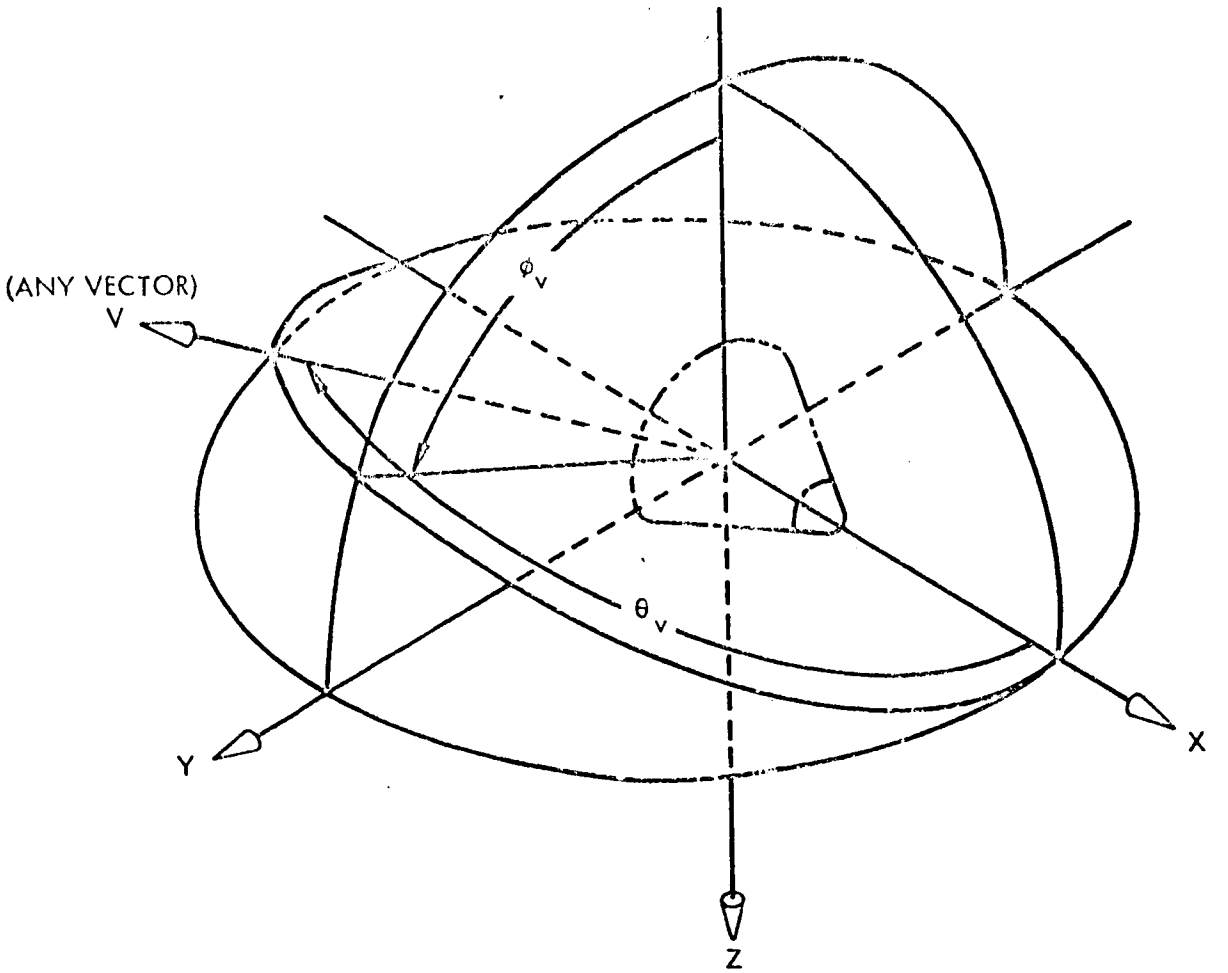


Figure 1. Local Horizontal Pitch as a Function of Inertial Pitch for Landing Site 2



ϕ_v MEASURED FROM MINUS Z-BODY AXIS POSITIVELY ABOUT X-BODY AXIS TO VECTOR PROJECTION IN Y-Z PLANE

θ_v SMALLEST ANGLE FROM X-BODY AXIS TO VECTOR

Figure 2. Spacecraft Look Angles

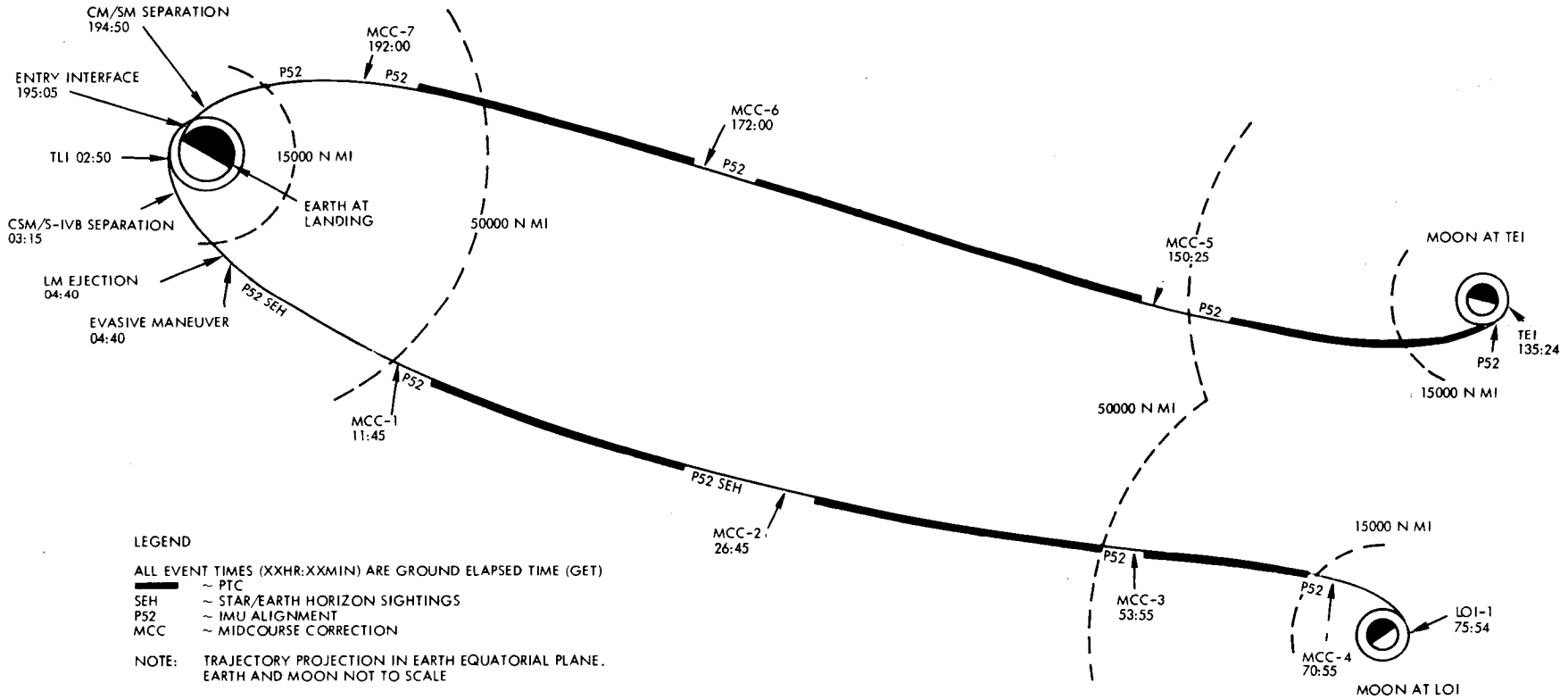


Figure 3. Cislunar Trajectory and Event Profile

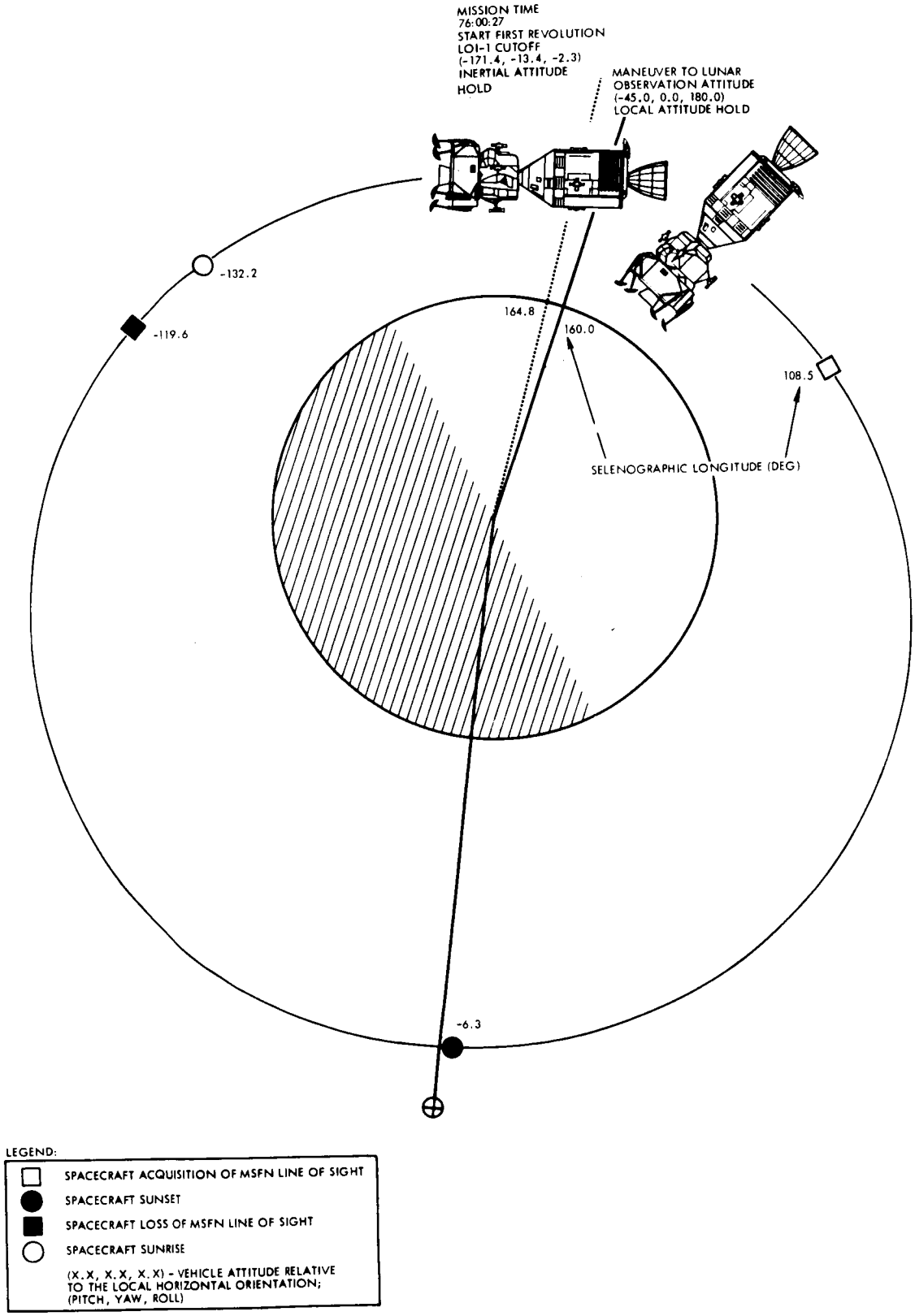


Figure 4. First Revolution Major Events and Attitudes

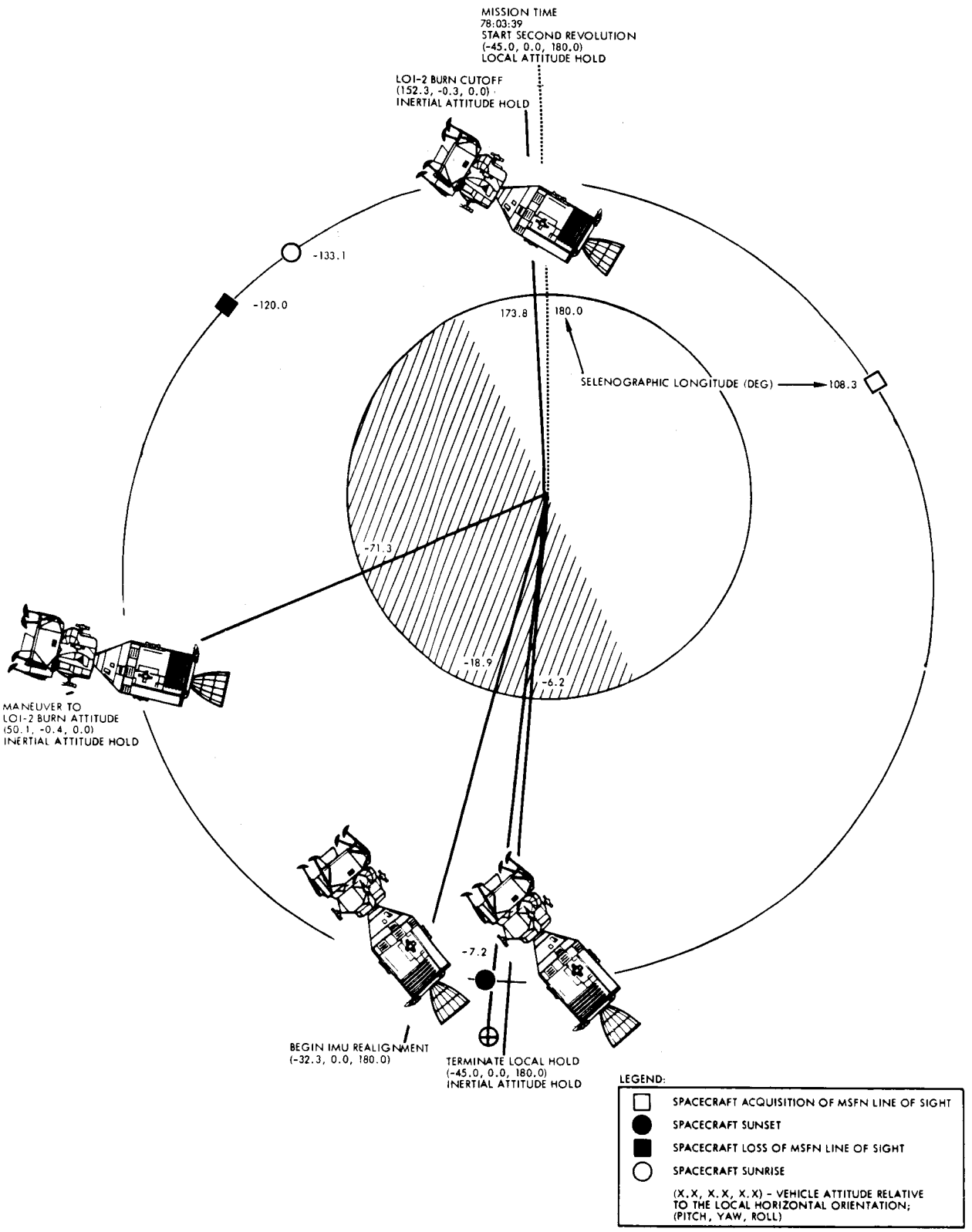


Figure 5. Second Revolution Major Events and Attitudes

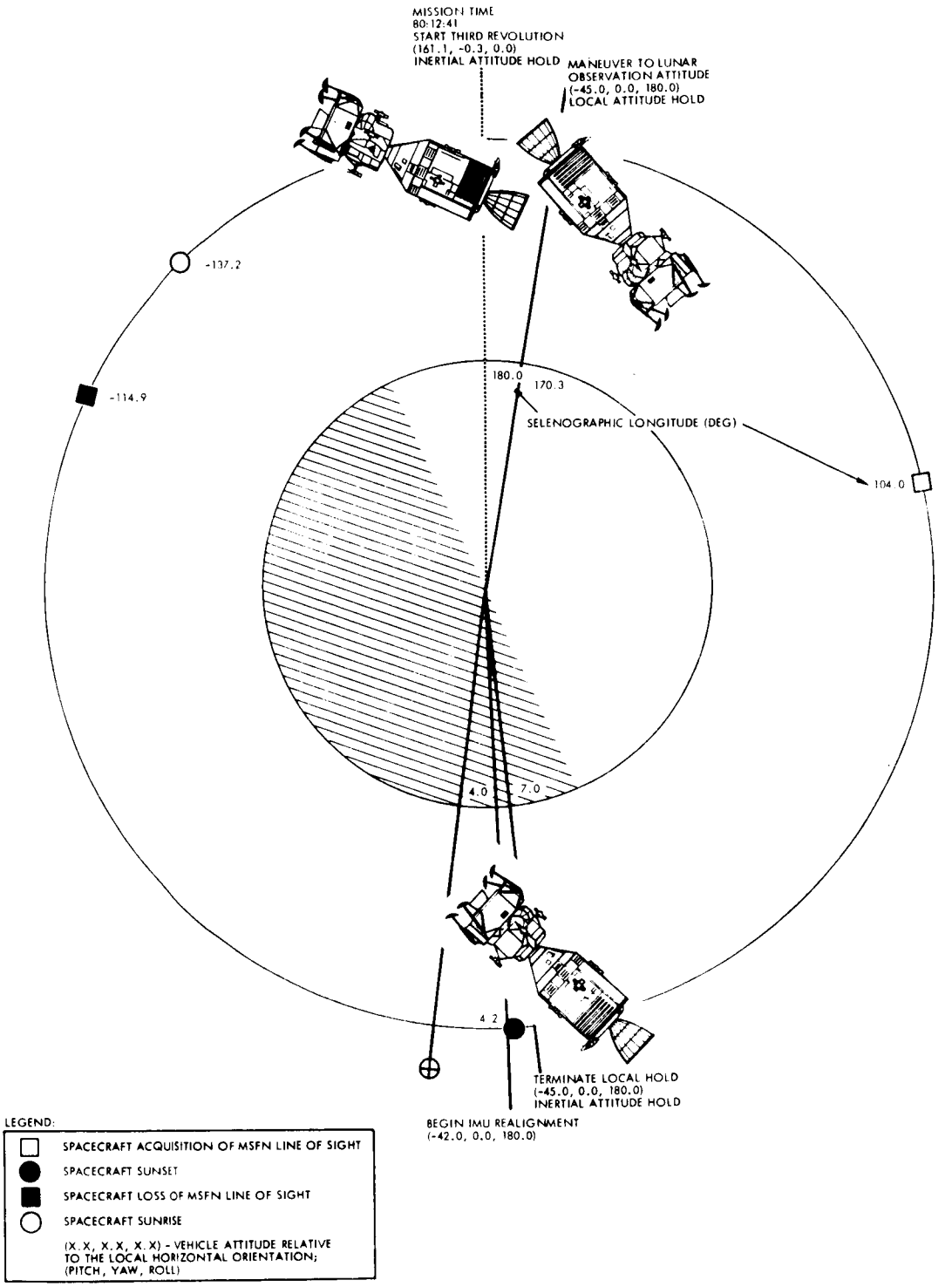


Figure 6. Third Revolution Major Events and Attitudes

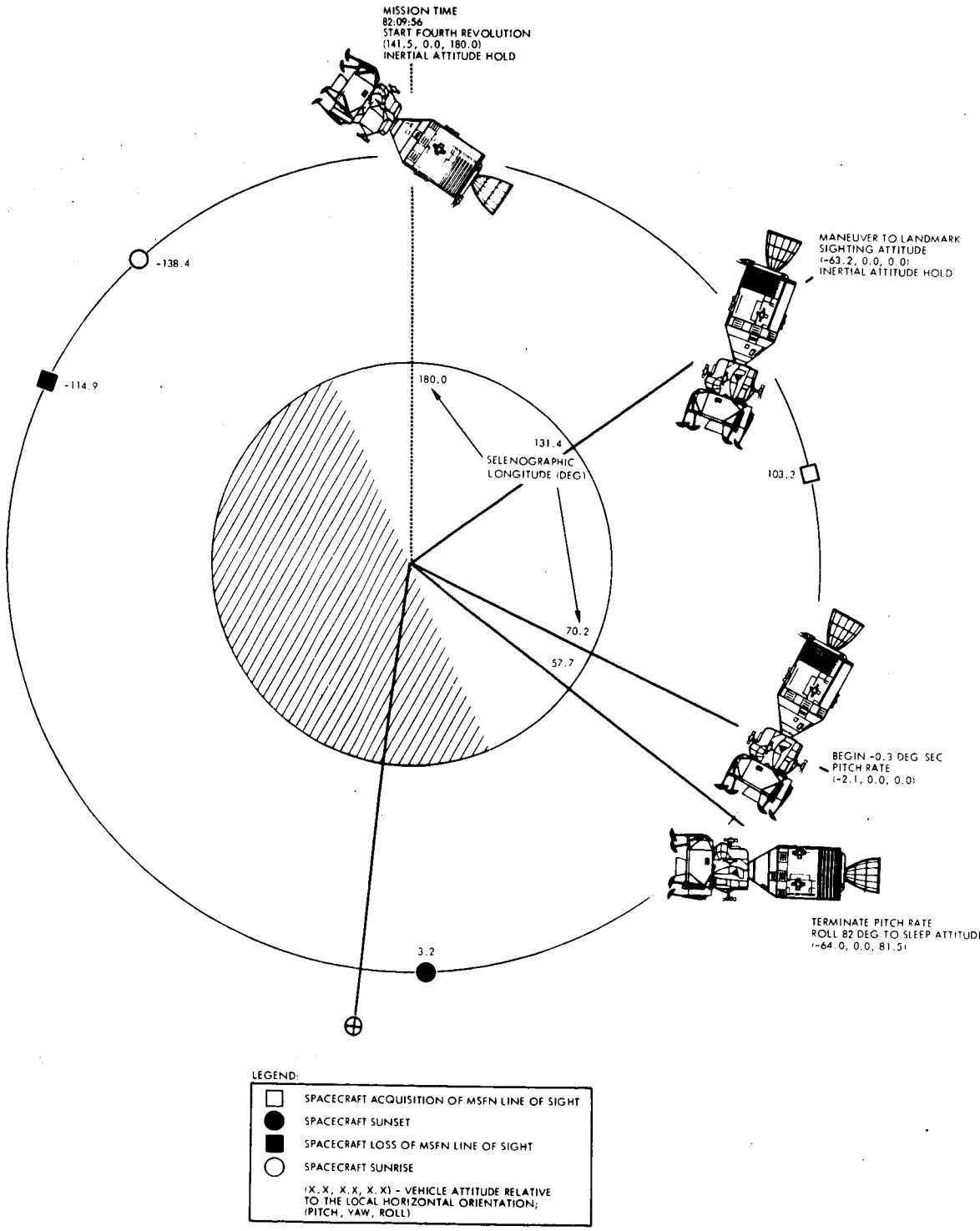


Figure 7. Fourth Revolution Major Events and Attitudes

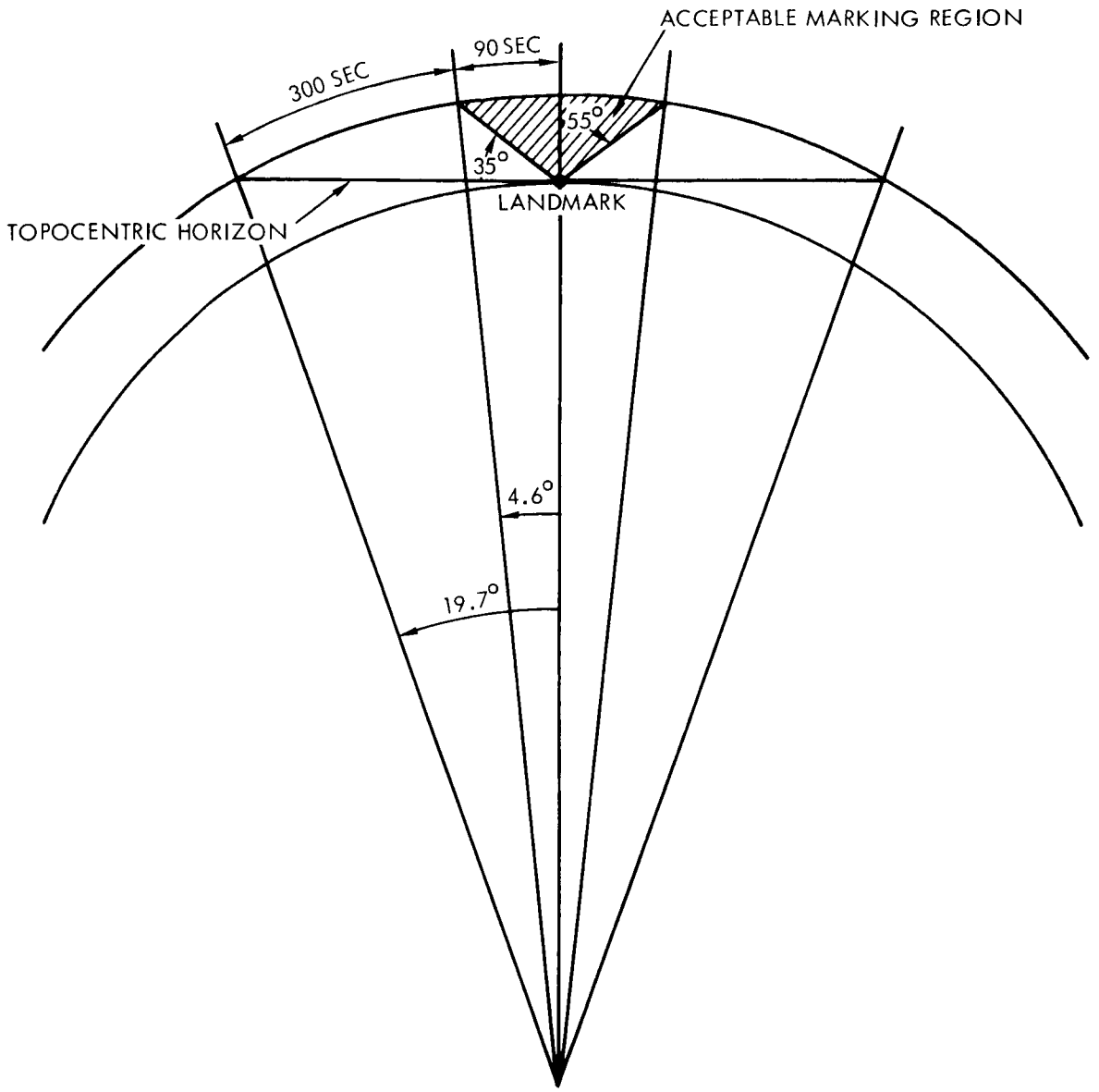


Figure 8. Landmark Tracking Geometry for a 60-Nautical Mile Circular Lunar Orbit

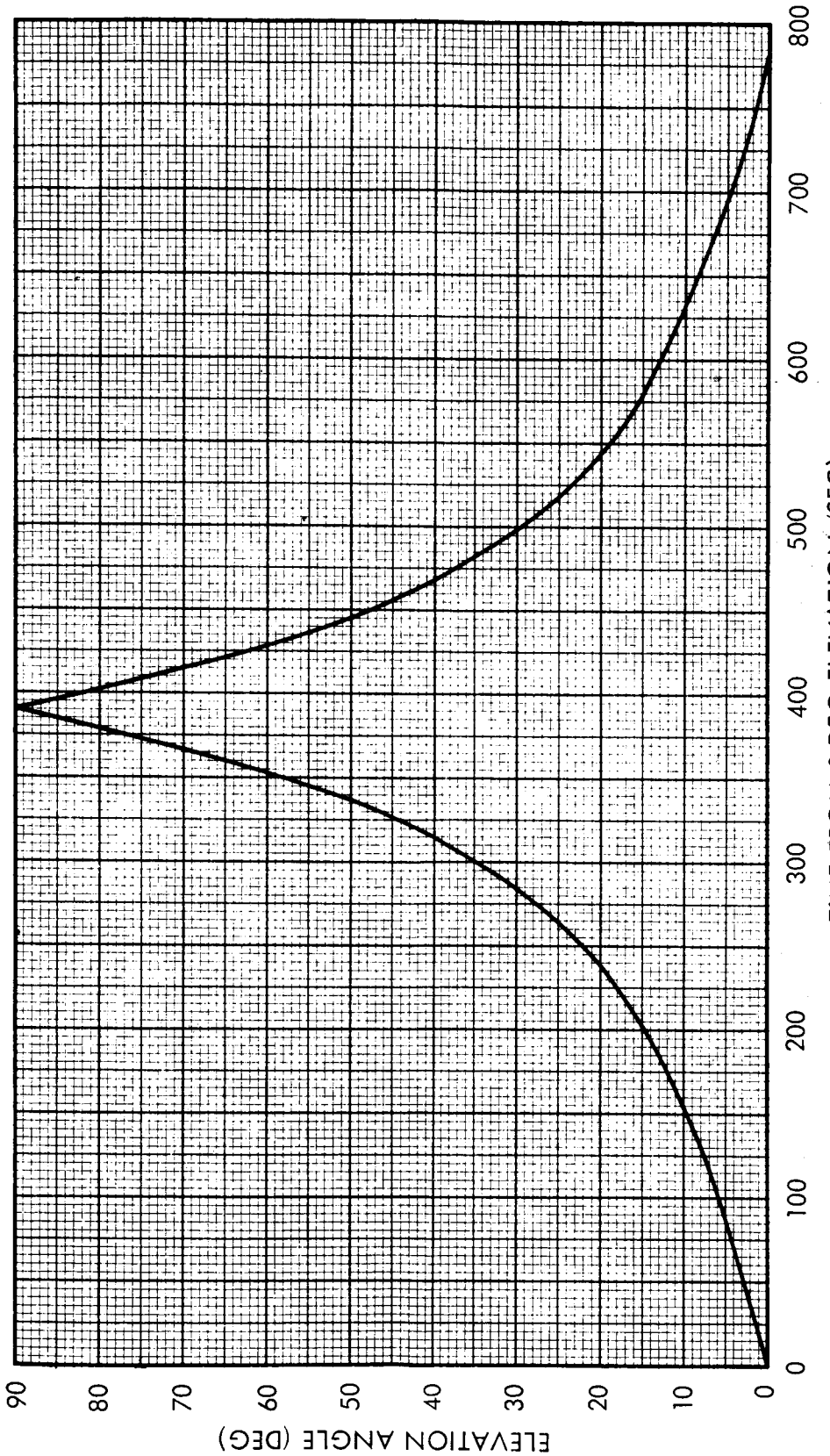


Figure 9. Elevation Angle versus Time Curve for In-Plane Landmark

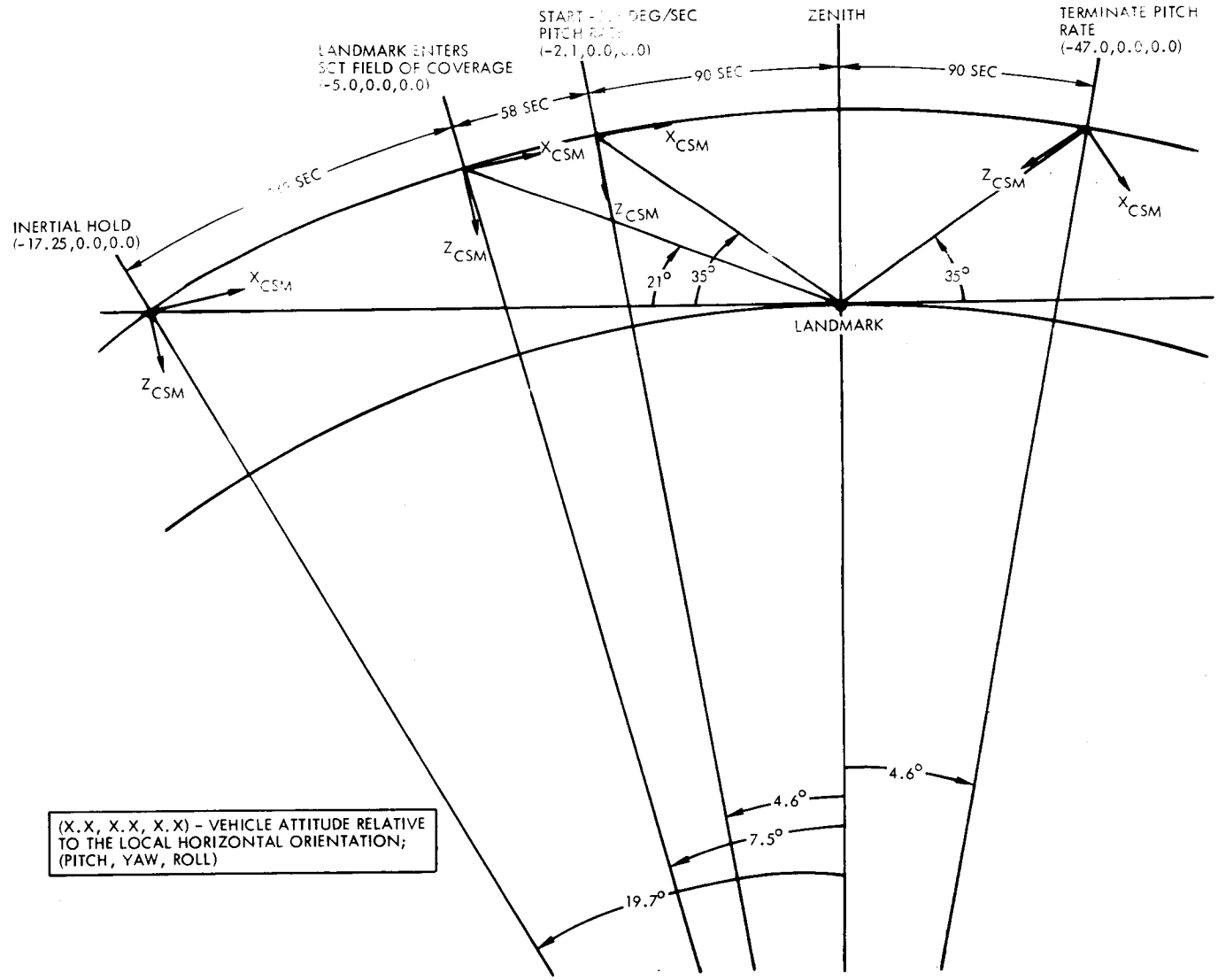


Figure 10. Tracking Geometry for Mode I Landmark Tracking

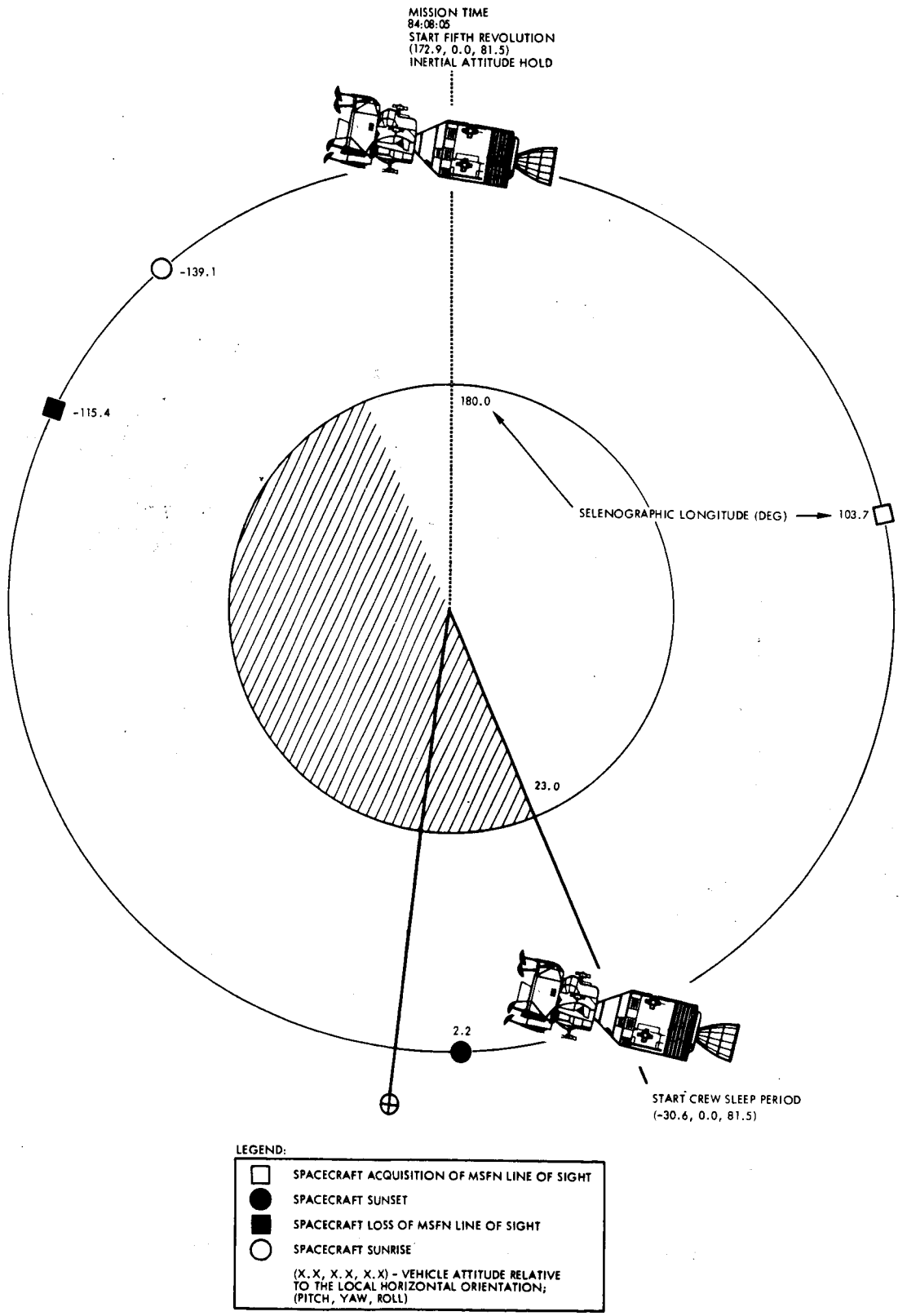


Figure 11. Fifth Revolution Major Events and Attitudes

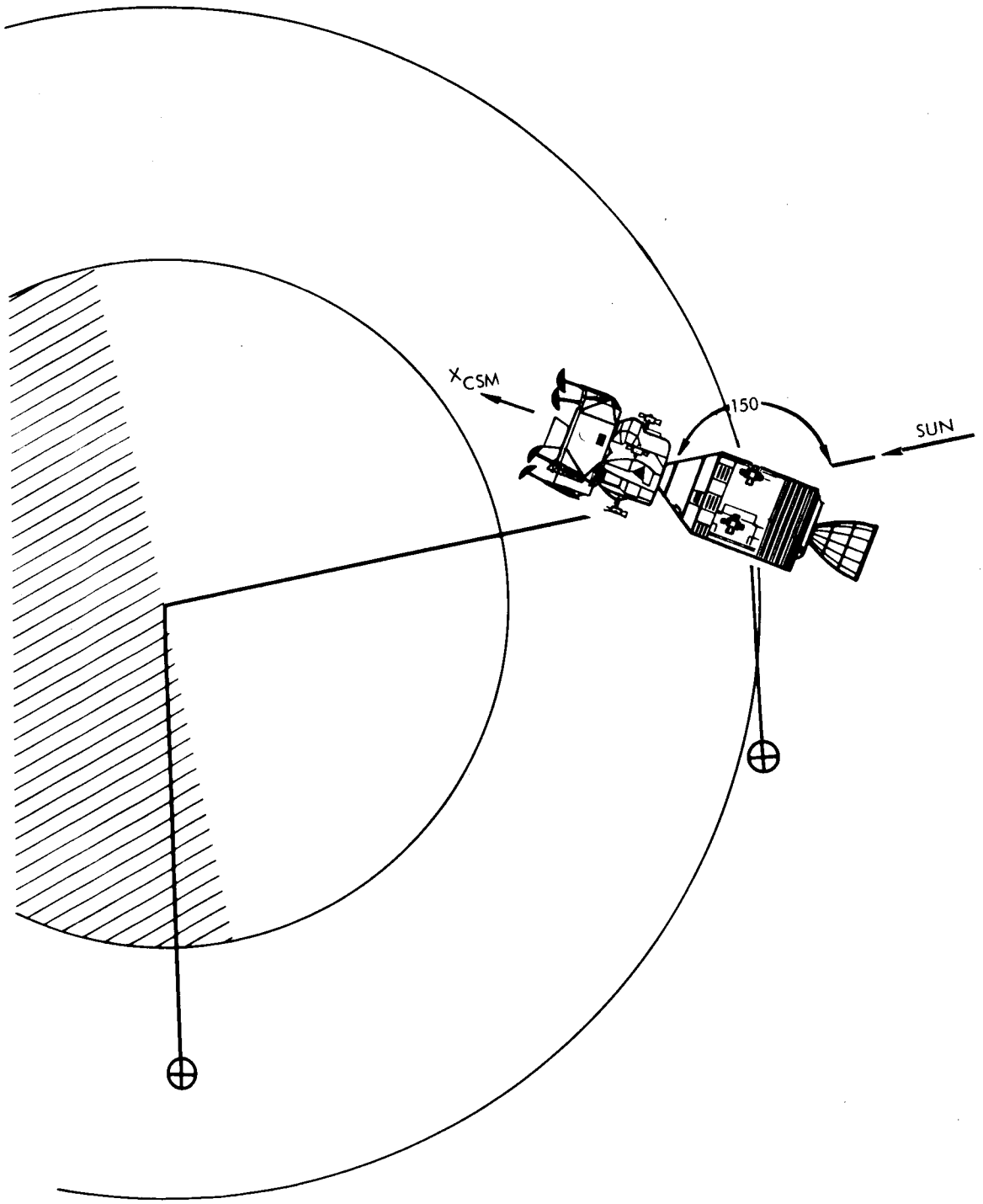


Figure 12. Lunar Orbit Sleep Geometry

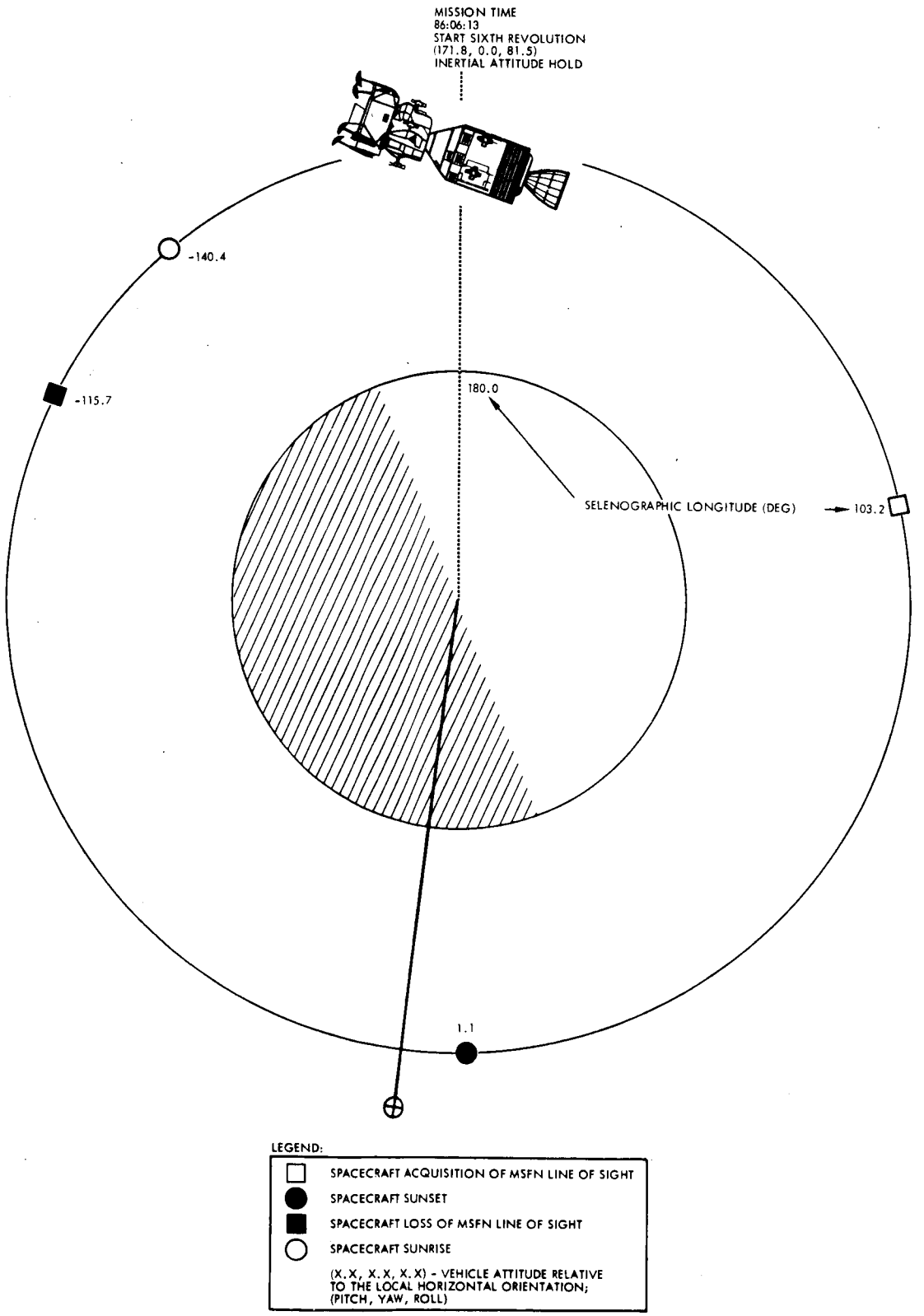


Figure 13. Sixth Revolution Major Events and Attitudes

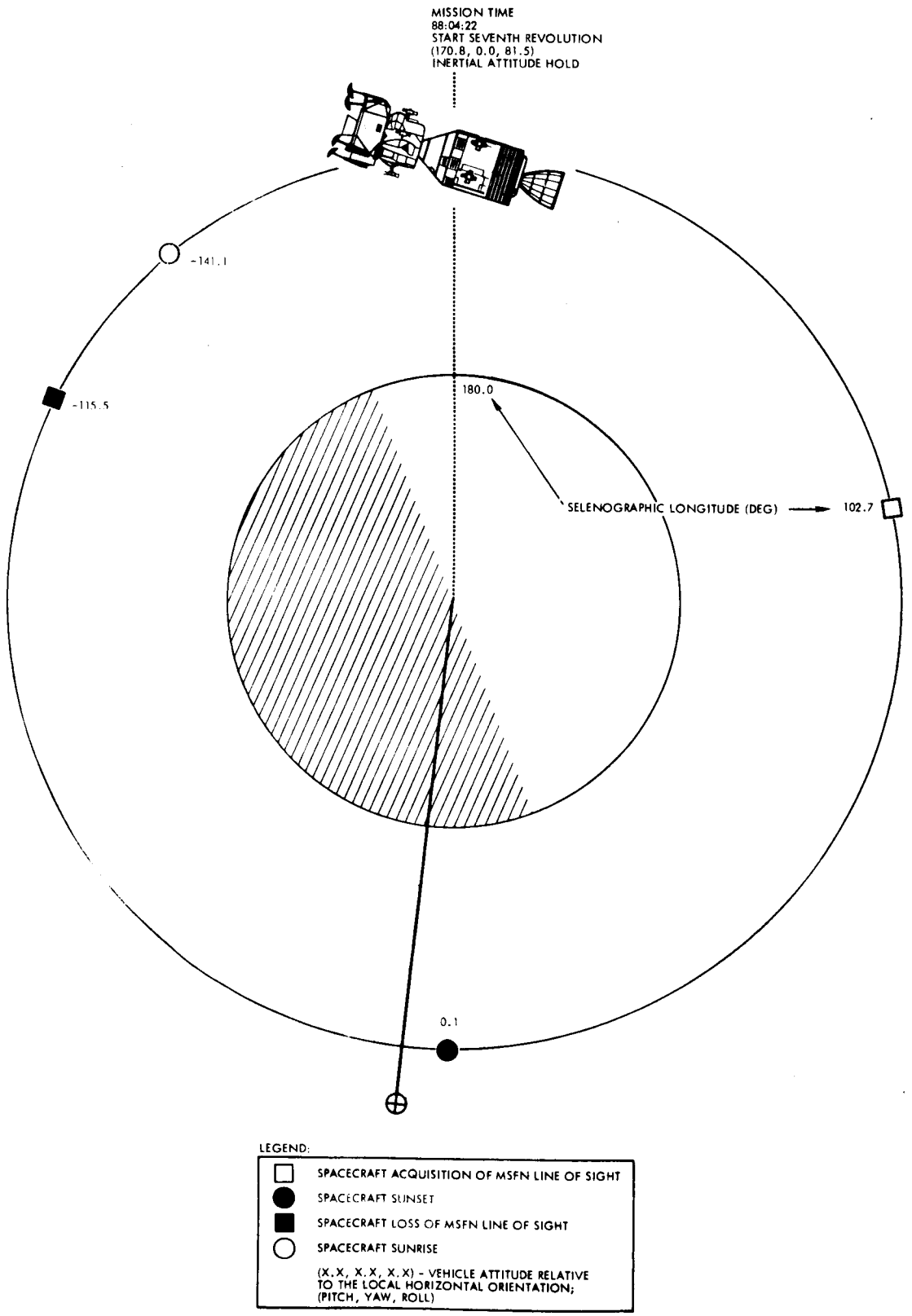


Figure 14. Seventh Revolution Major Events and Attitudes

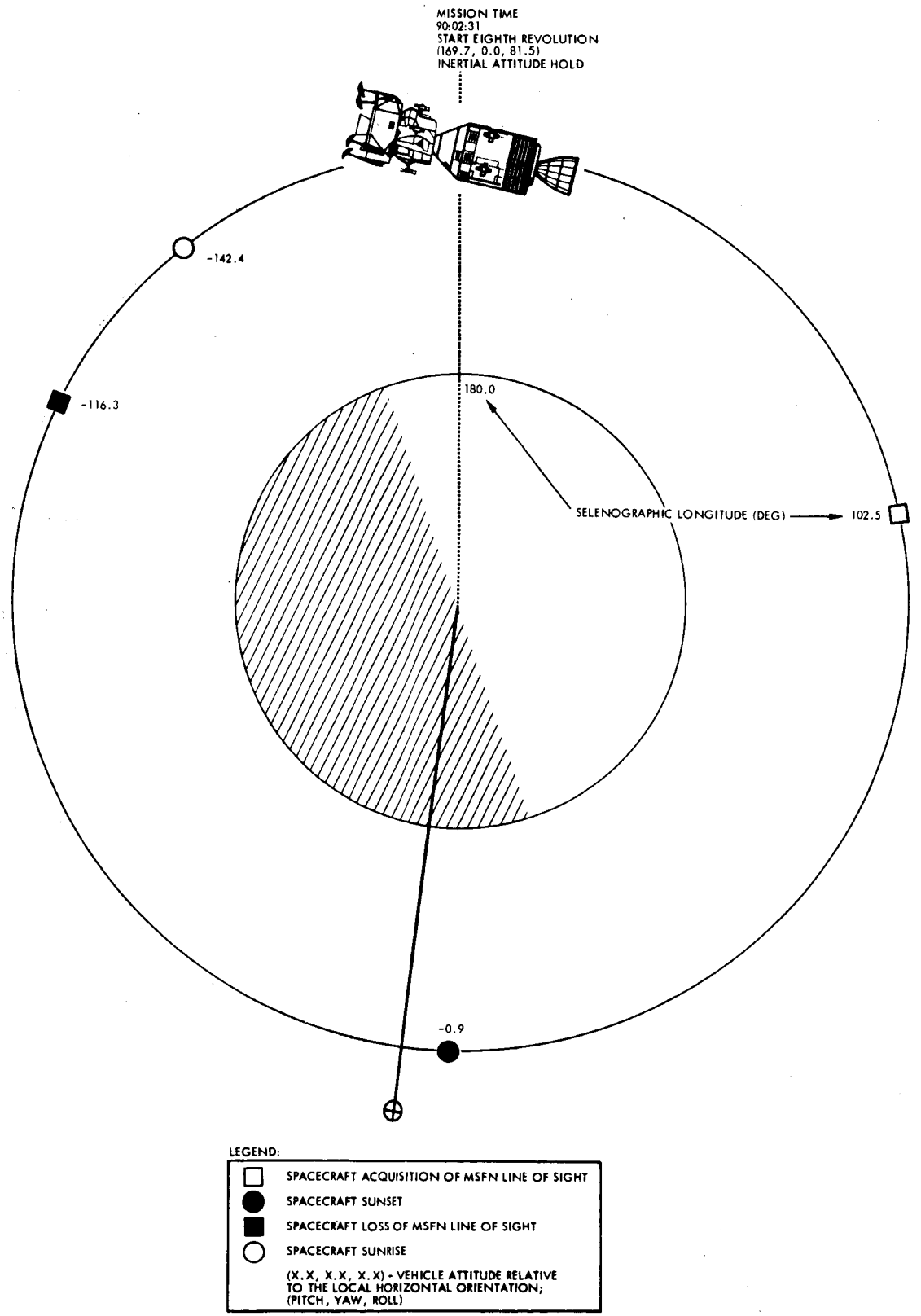


Figure 15. Eighth Revolution Major Events and Attitudes

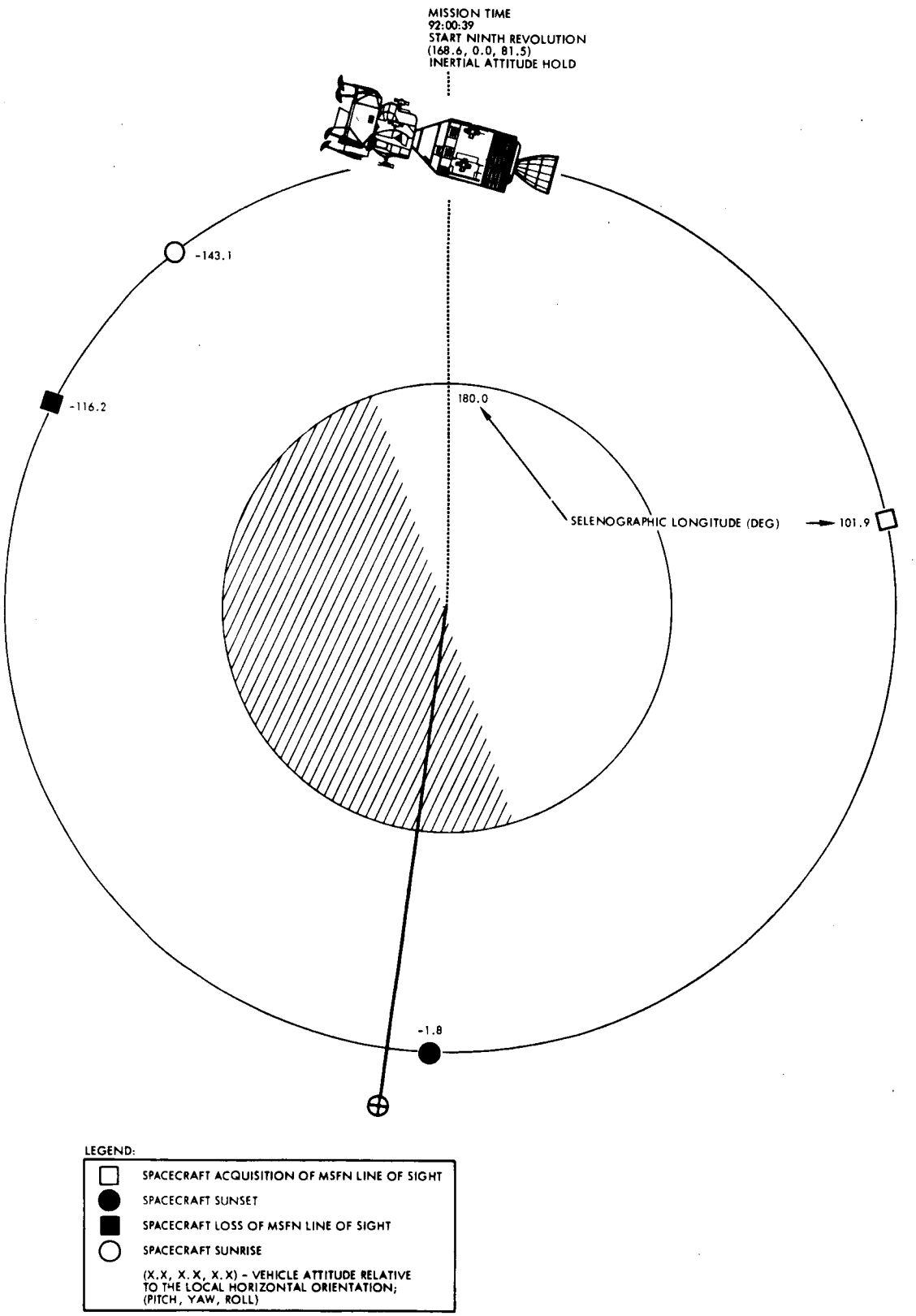


Figure 16. Ninth Revolution Major Events and Attitudes

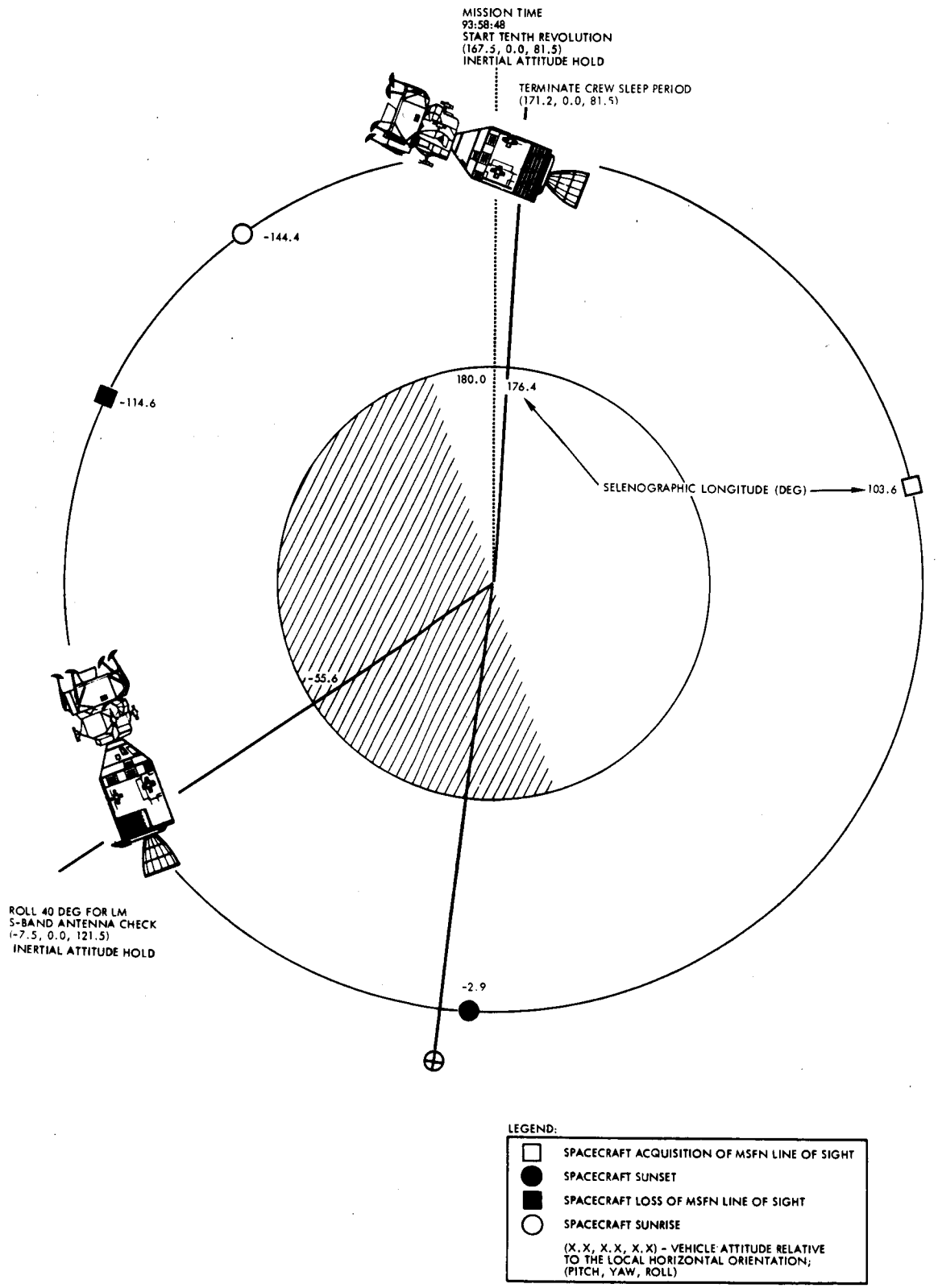


Figure 17. Tenth Revolution Major Events and Attitudes

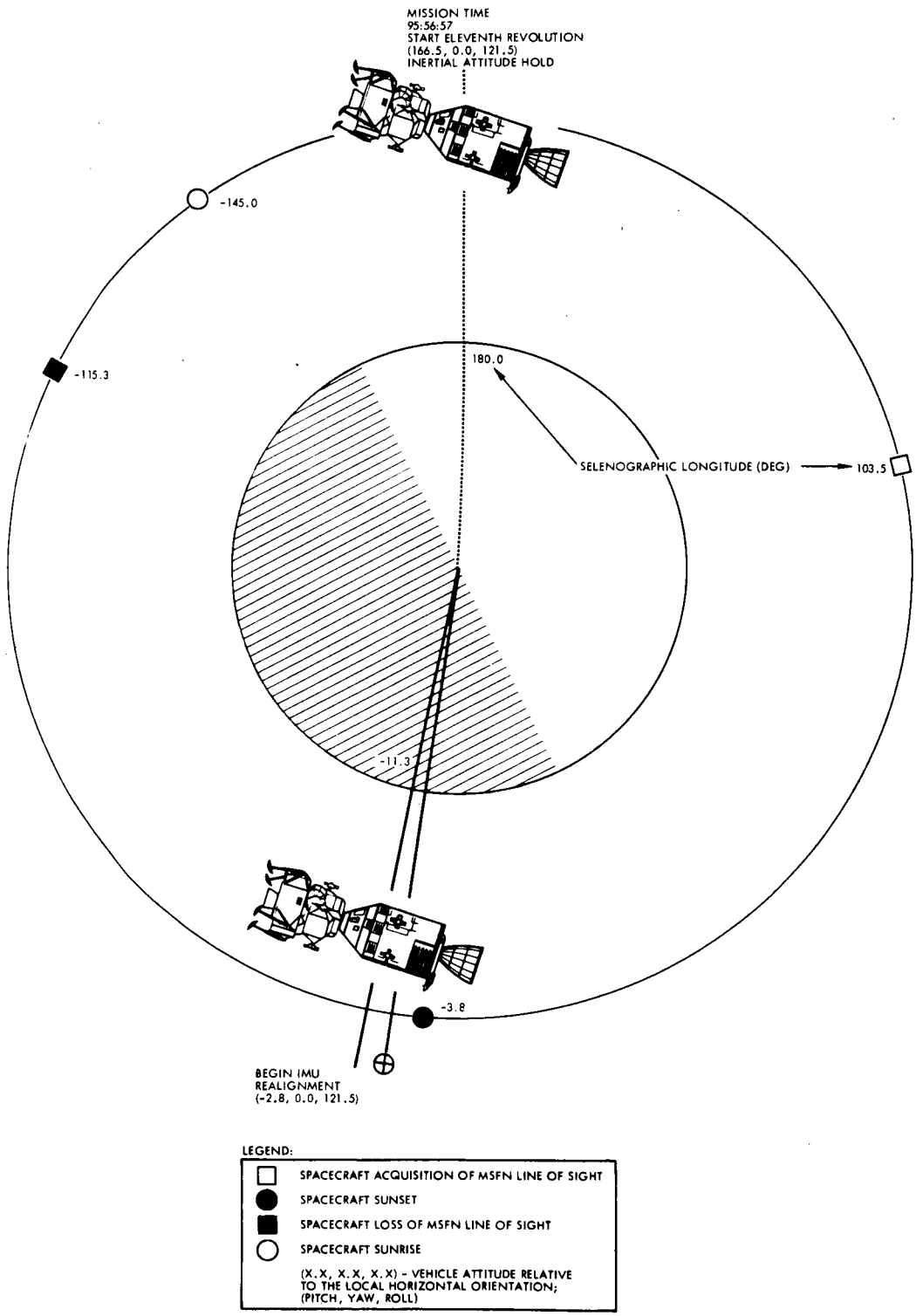


Figure 18. Eleventh Revolution Major Events and Attitudes

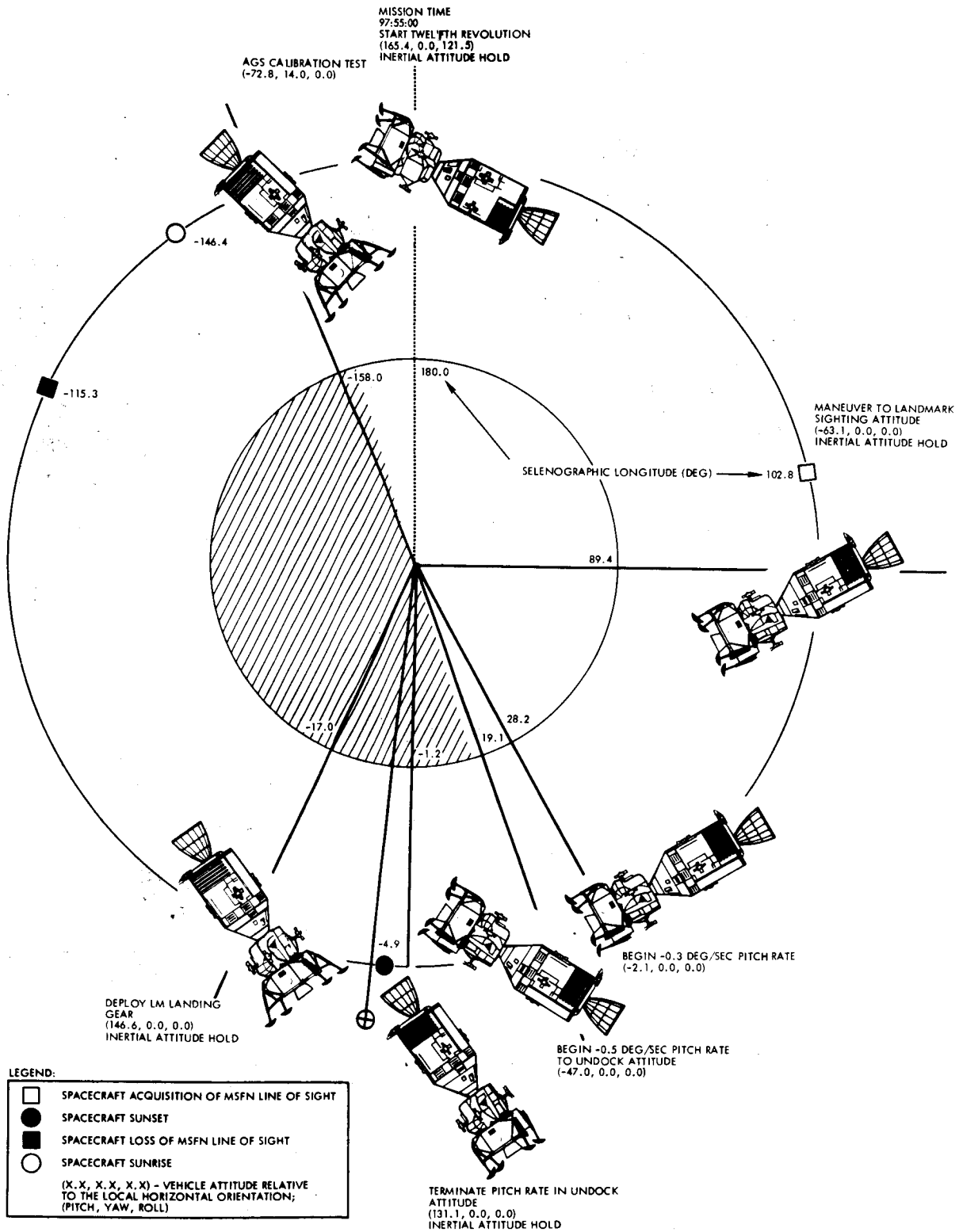


Figure 19. Twelfth Revolution Major Events and Attitudes

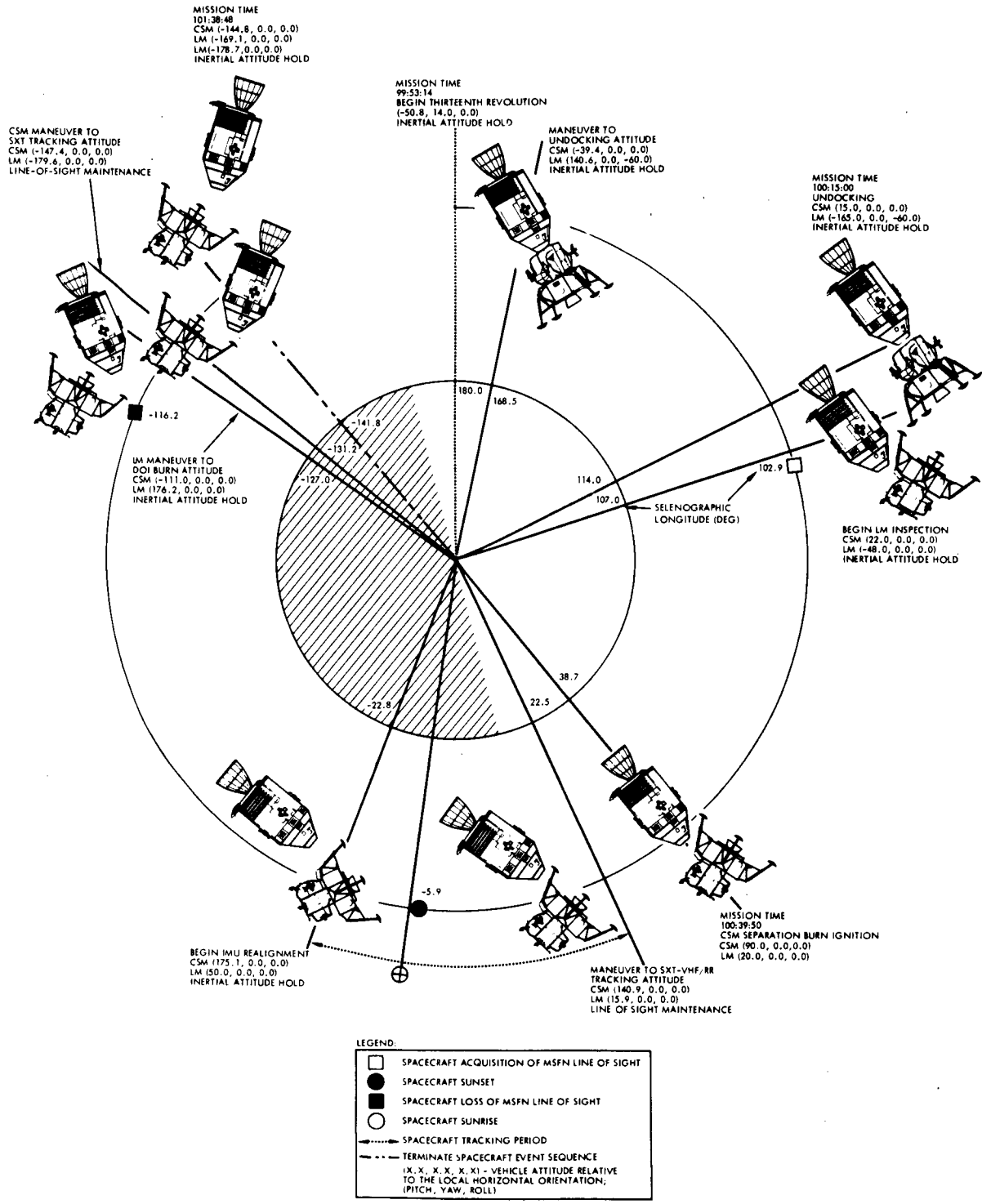


Figure 20. Thirteenth Revolution to DOI Burn Ignition

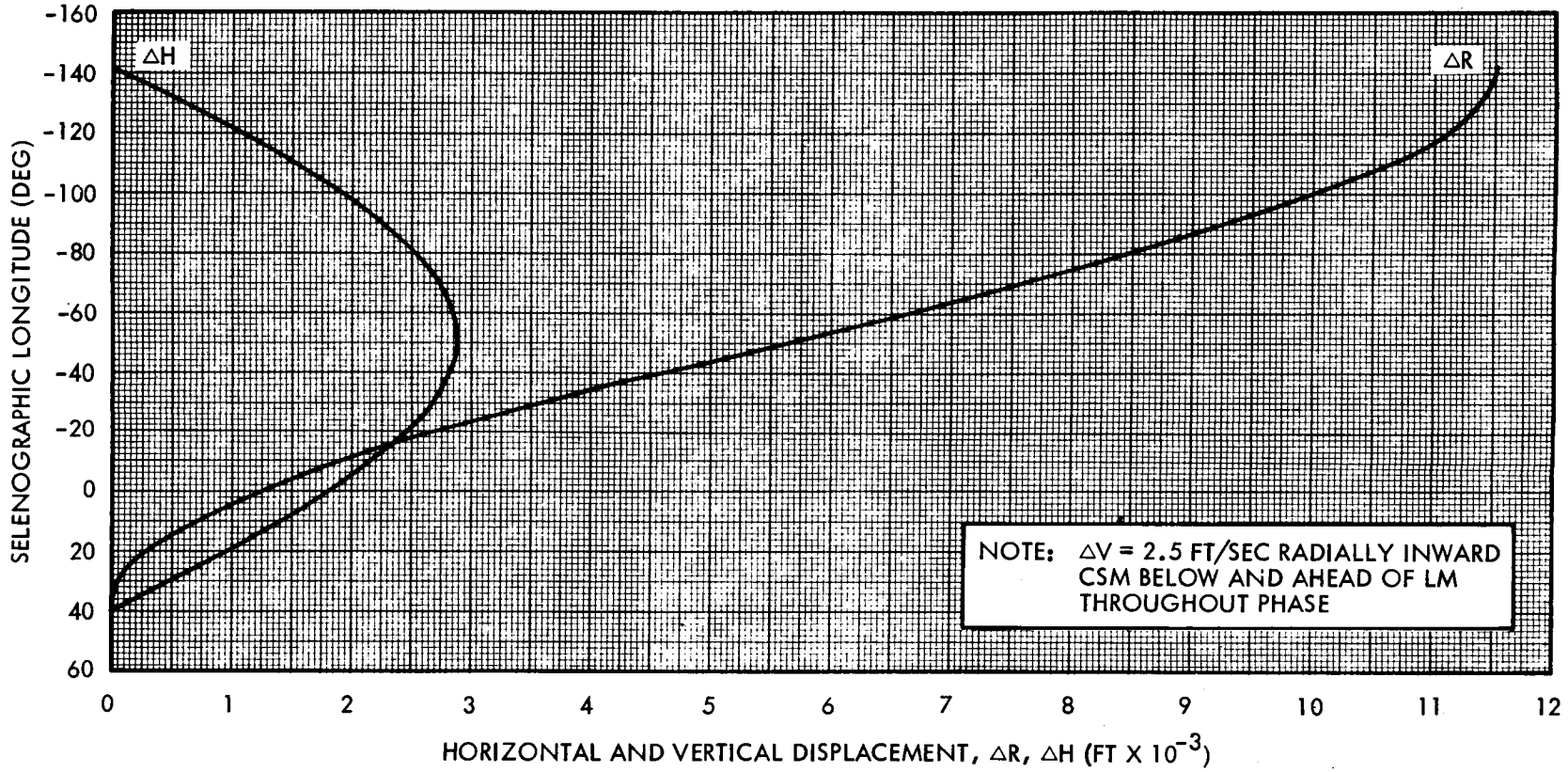


Figure 21. CSM-LM Relative Motion from Separation to DOI (LM Fixed)

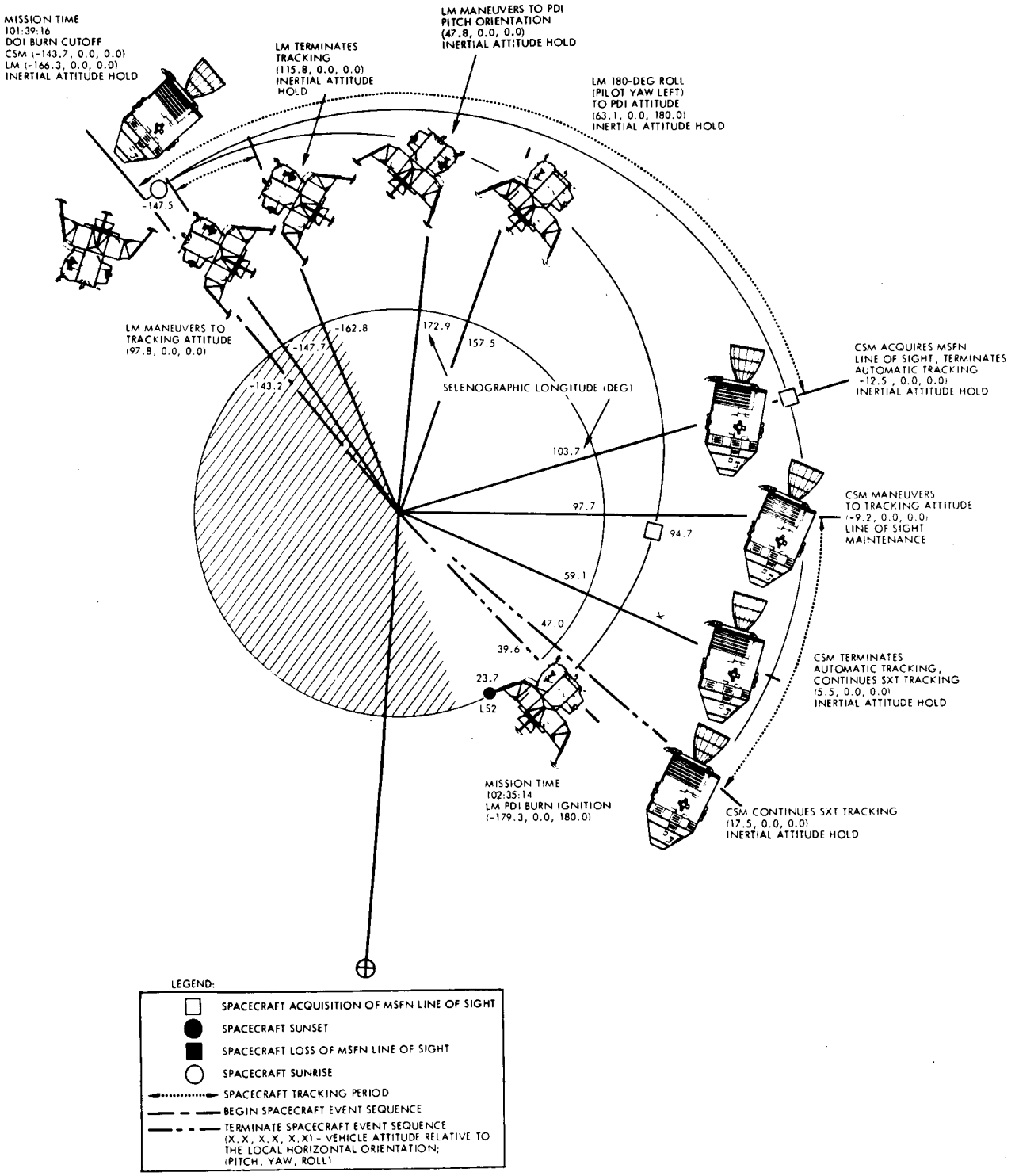


Figure 22. DOI Burn Cutoff to PDI Burn Ignition

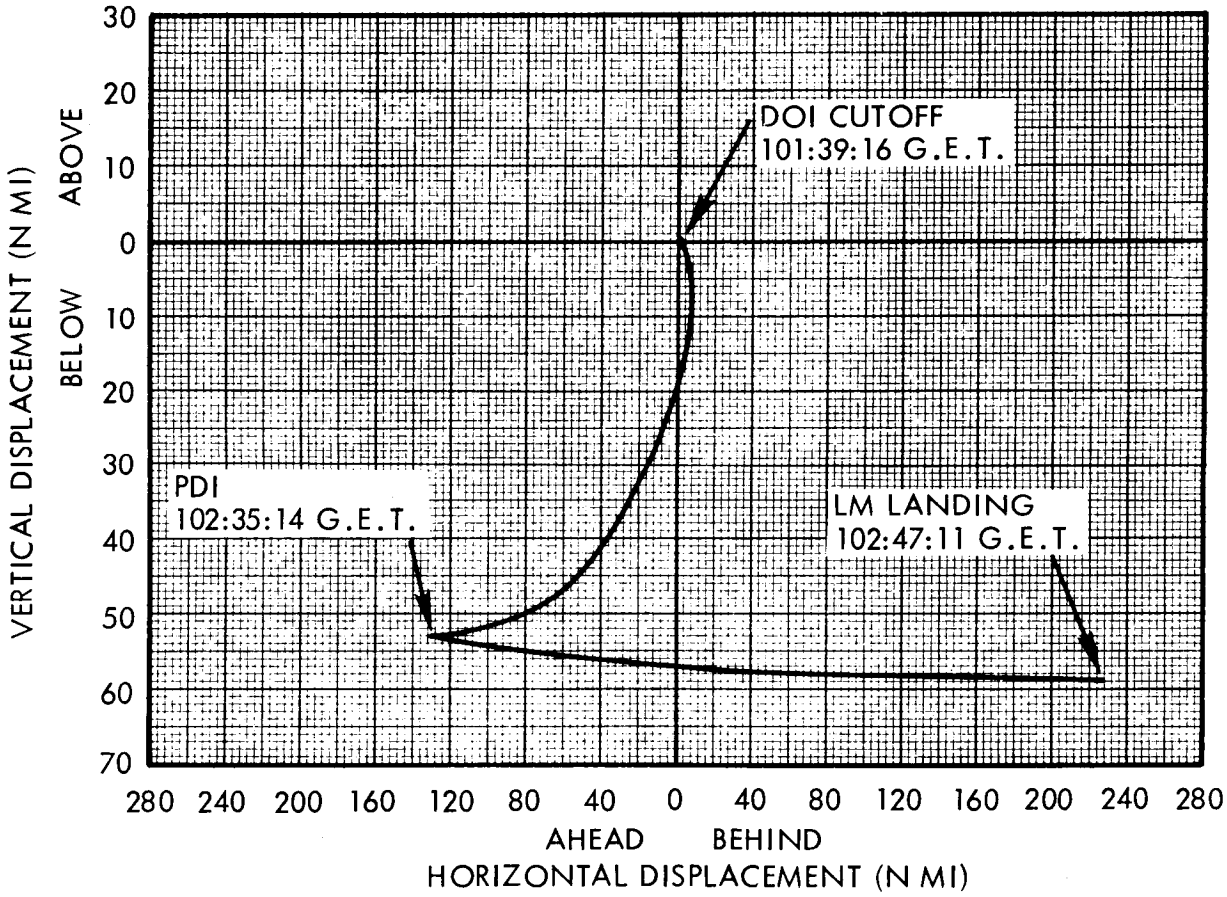


Figure 23. CSM-LM Relative Motion from DOI Burn Cut-off to LM Landing (CSM Fixed)

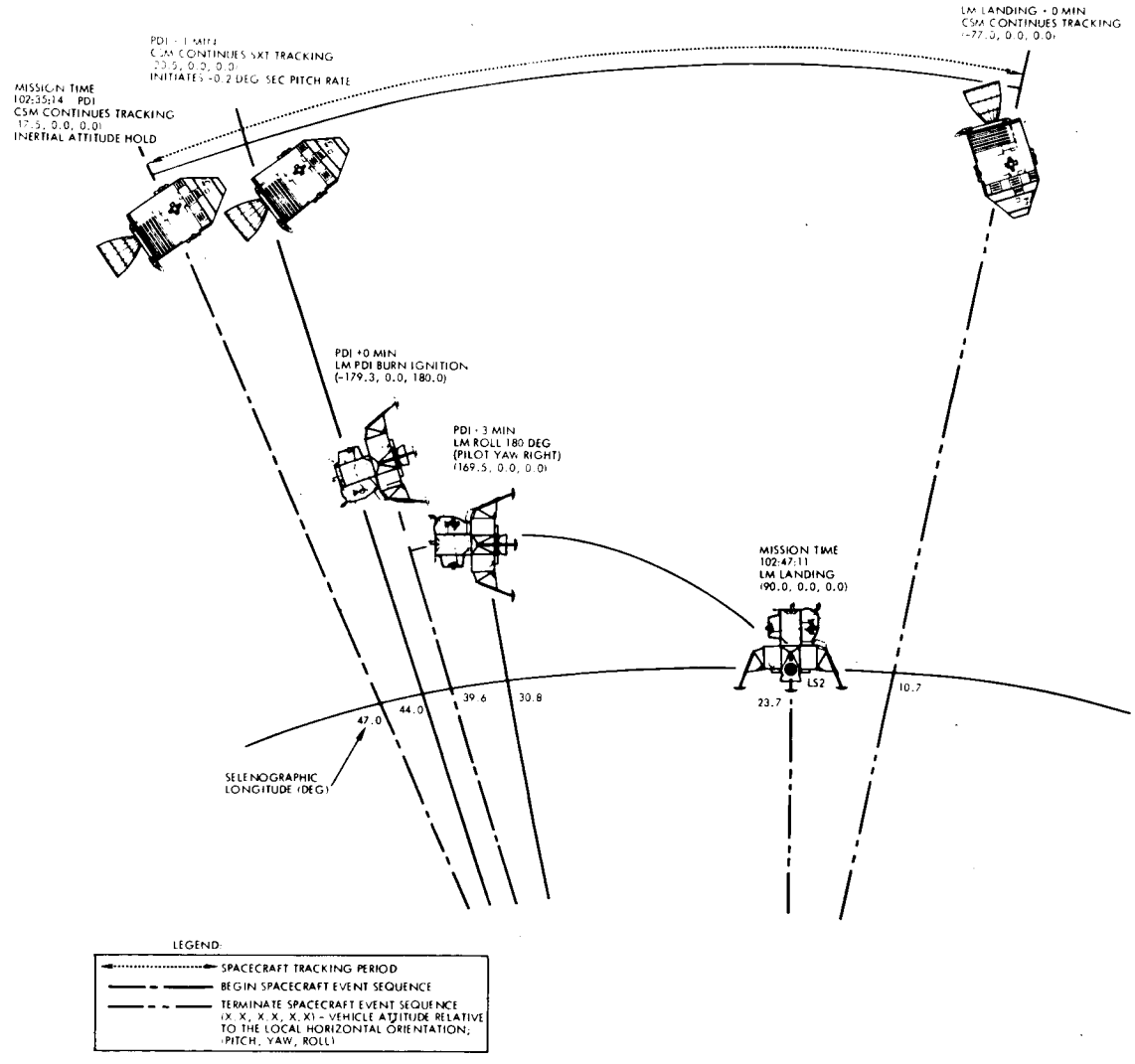


Figure 24. PDI Burn Ignition to LM Landing

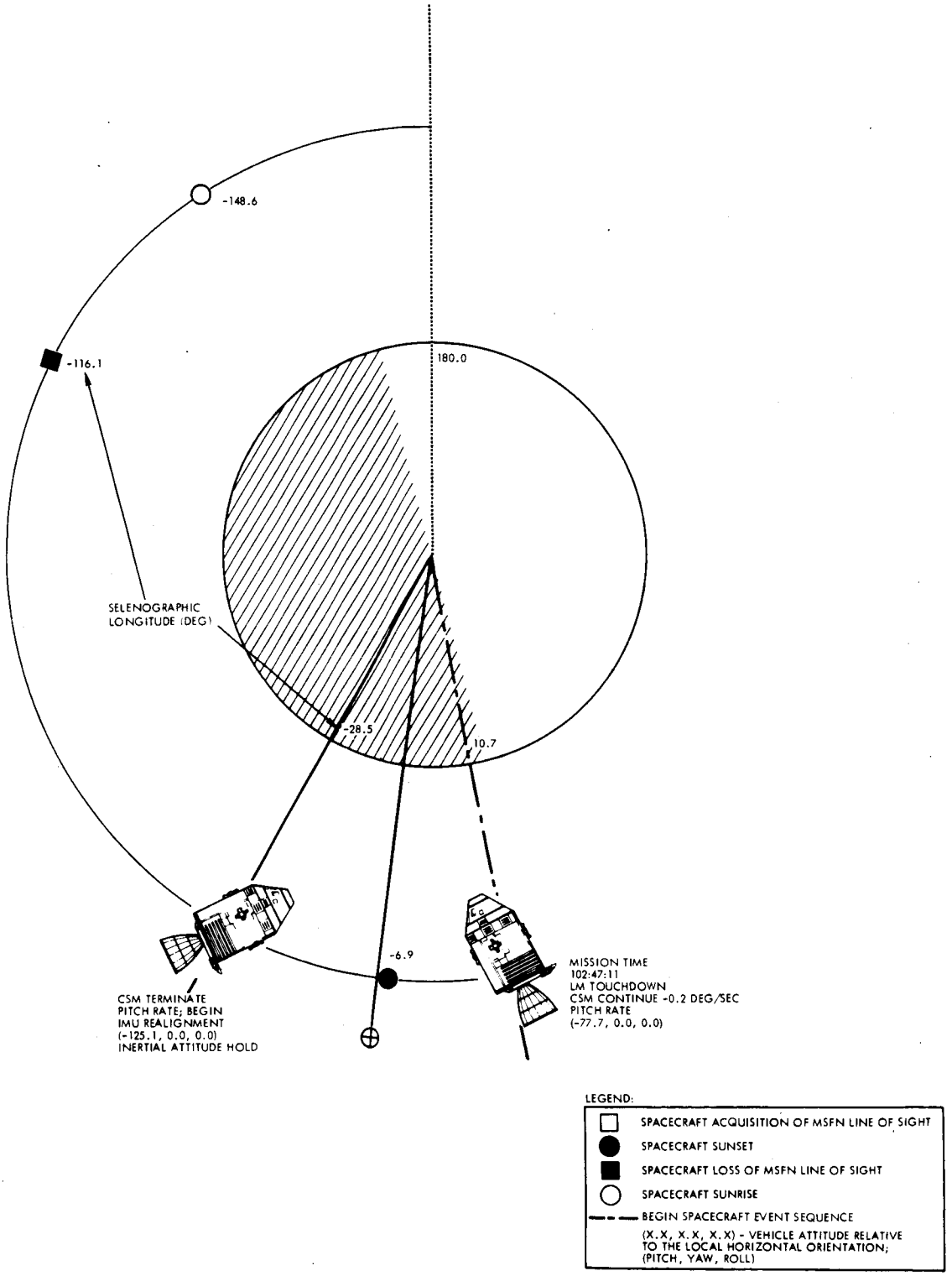


Figure 25. LM Landing to the Initiation of the Fifteenth Revolution

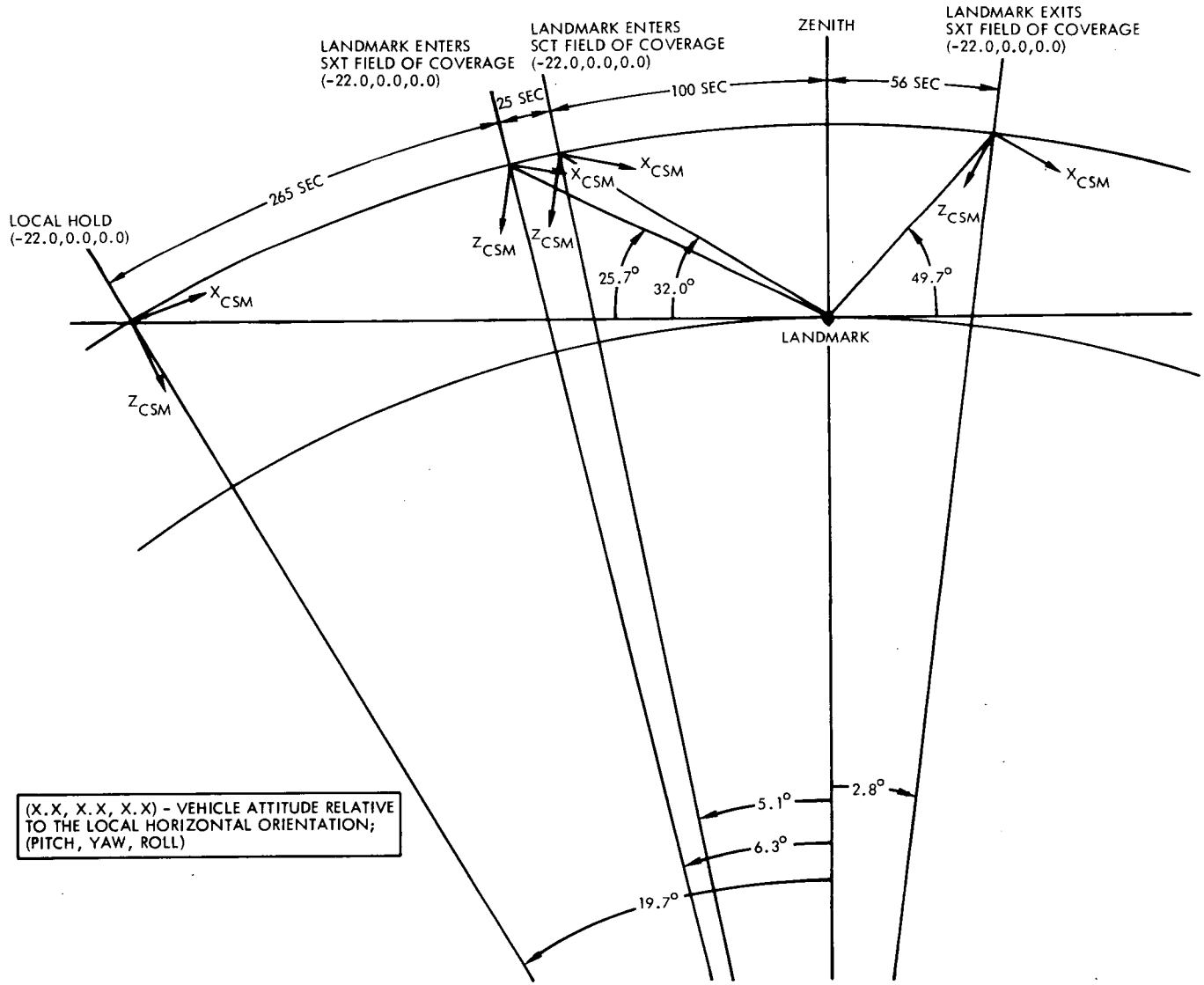


Figure 26. Tracking Geometry for Mode III Undocked Landmark Tracking

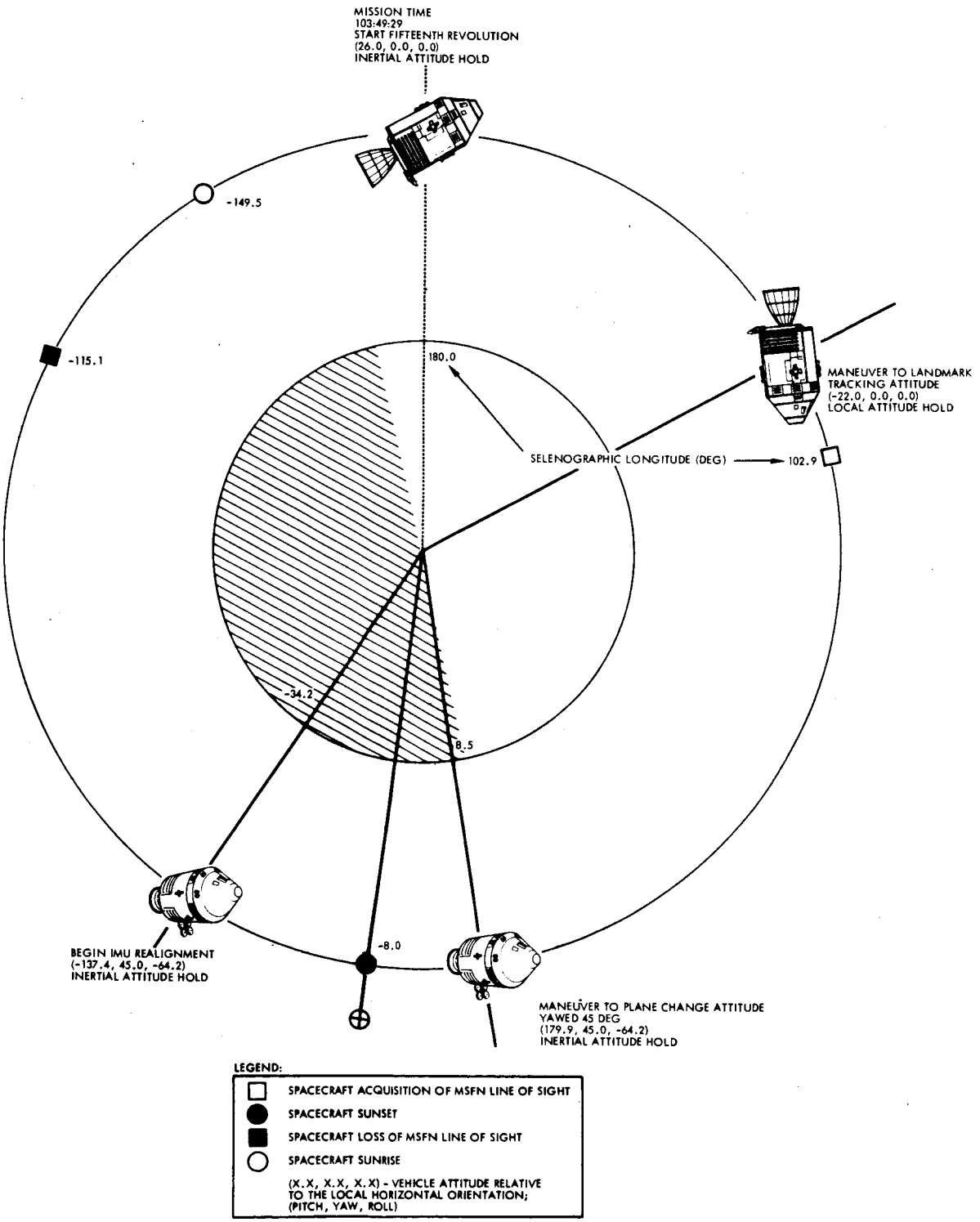


Figure 27. Fifteenth Revolution Major Events and Attitudes

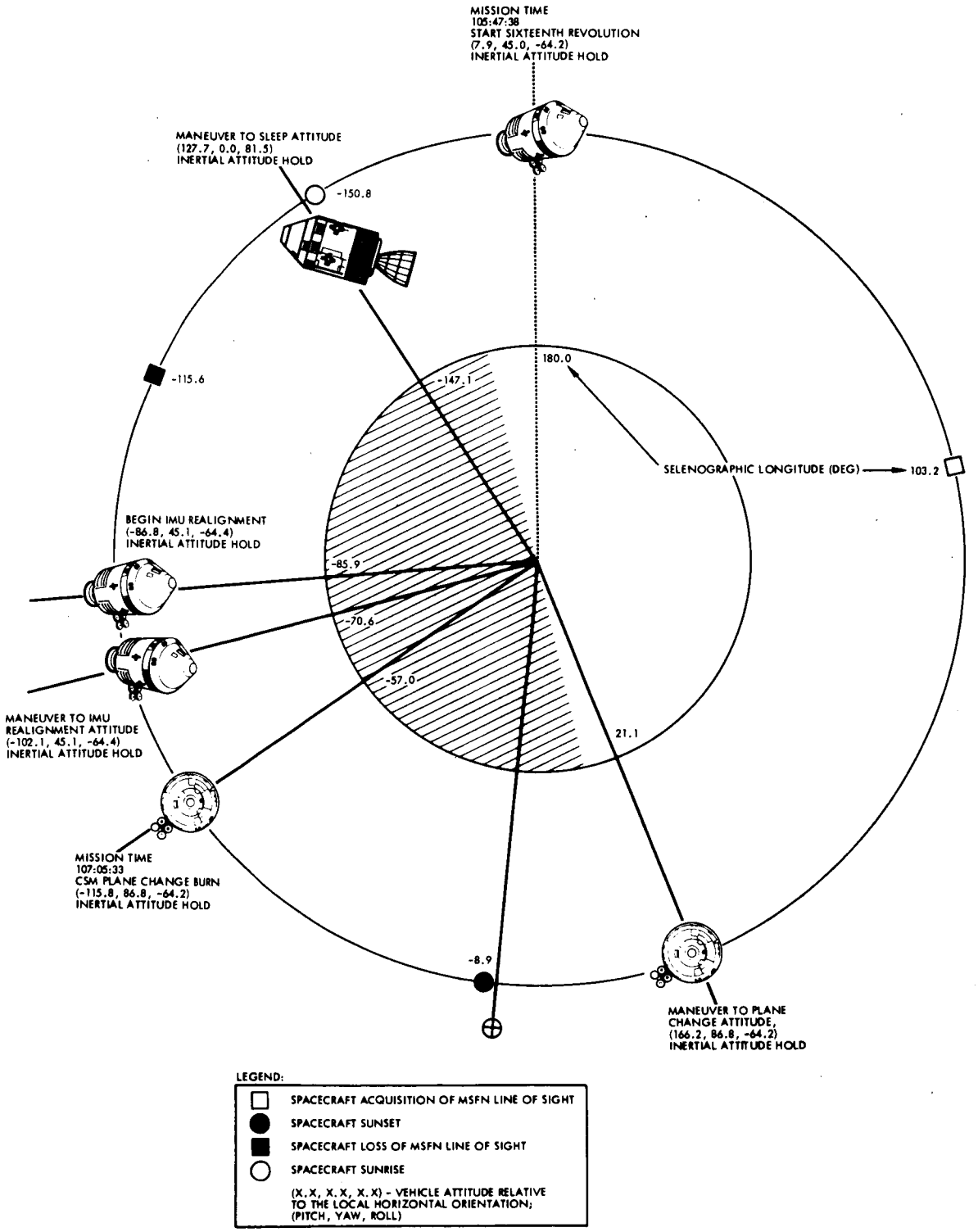


Figure 28. Sixteenth Revolution Major Events and Attitudes

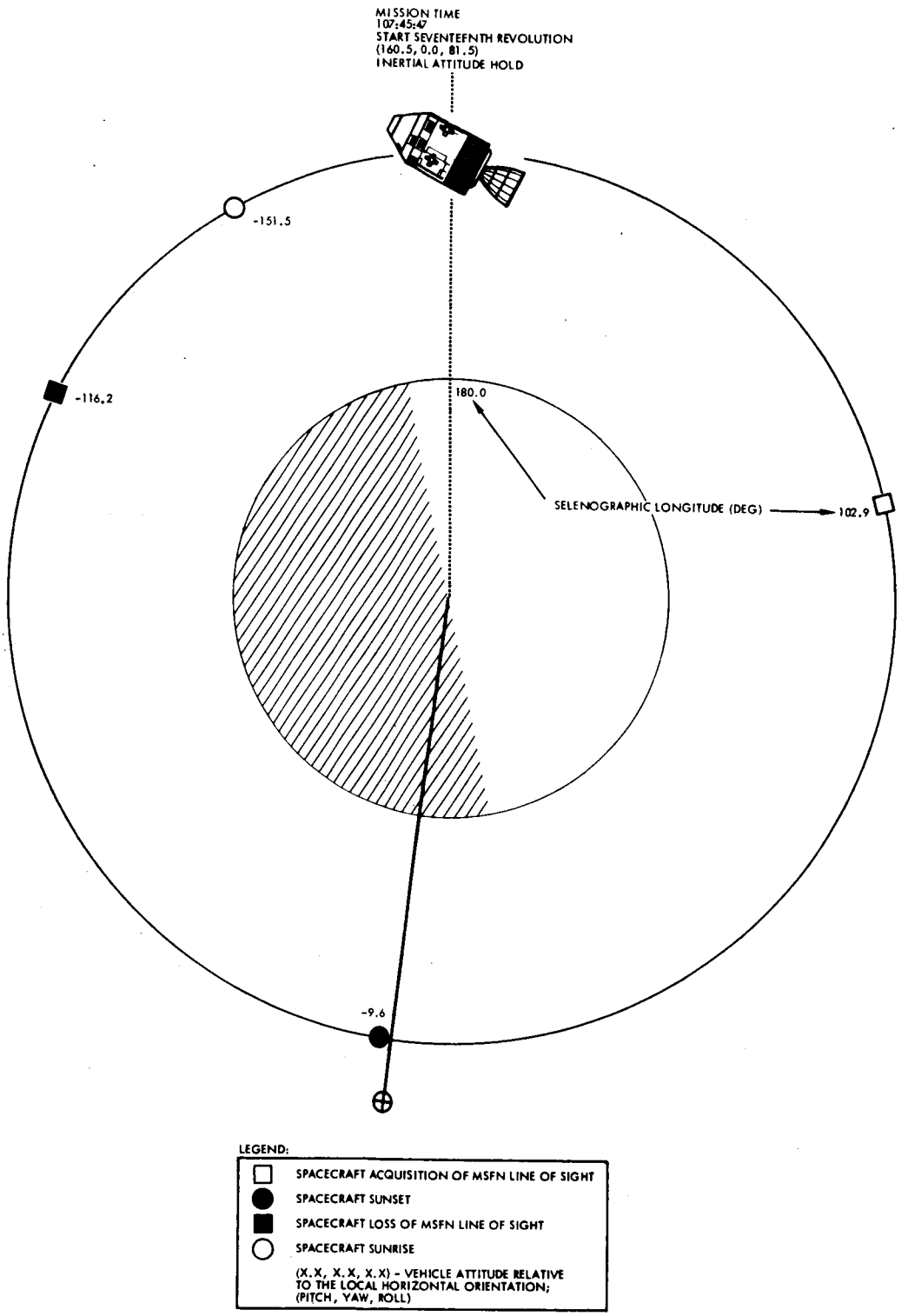


Figure 29. Seventeenth Revolution Major Events and Attitudes

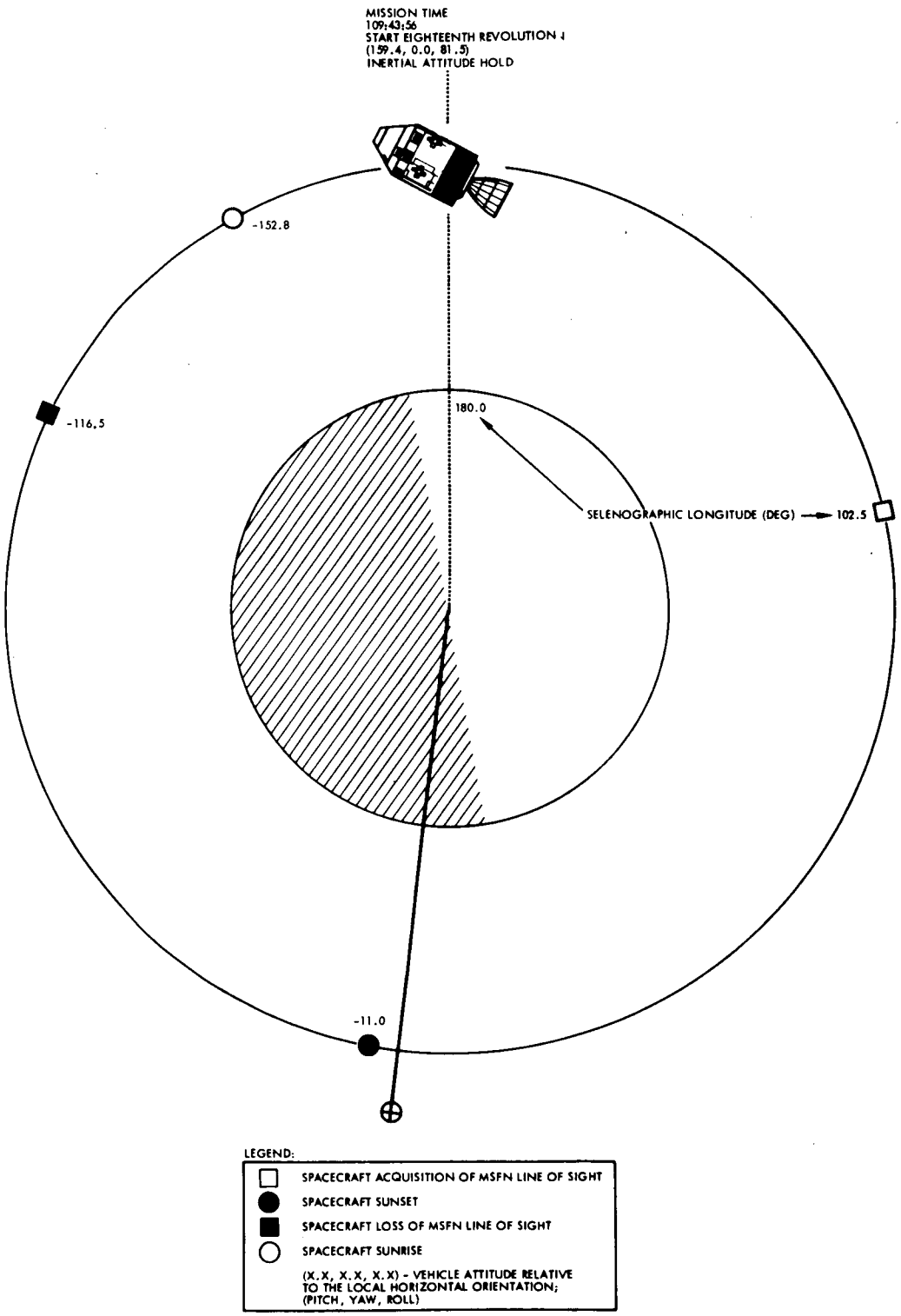


Figure 30. Eighteenth Revolution Major Events and Attitudes

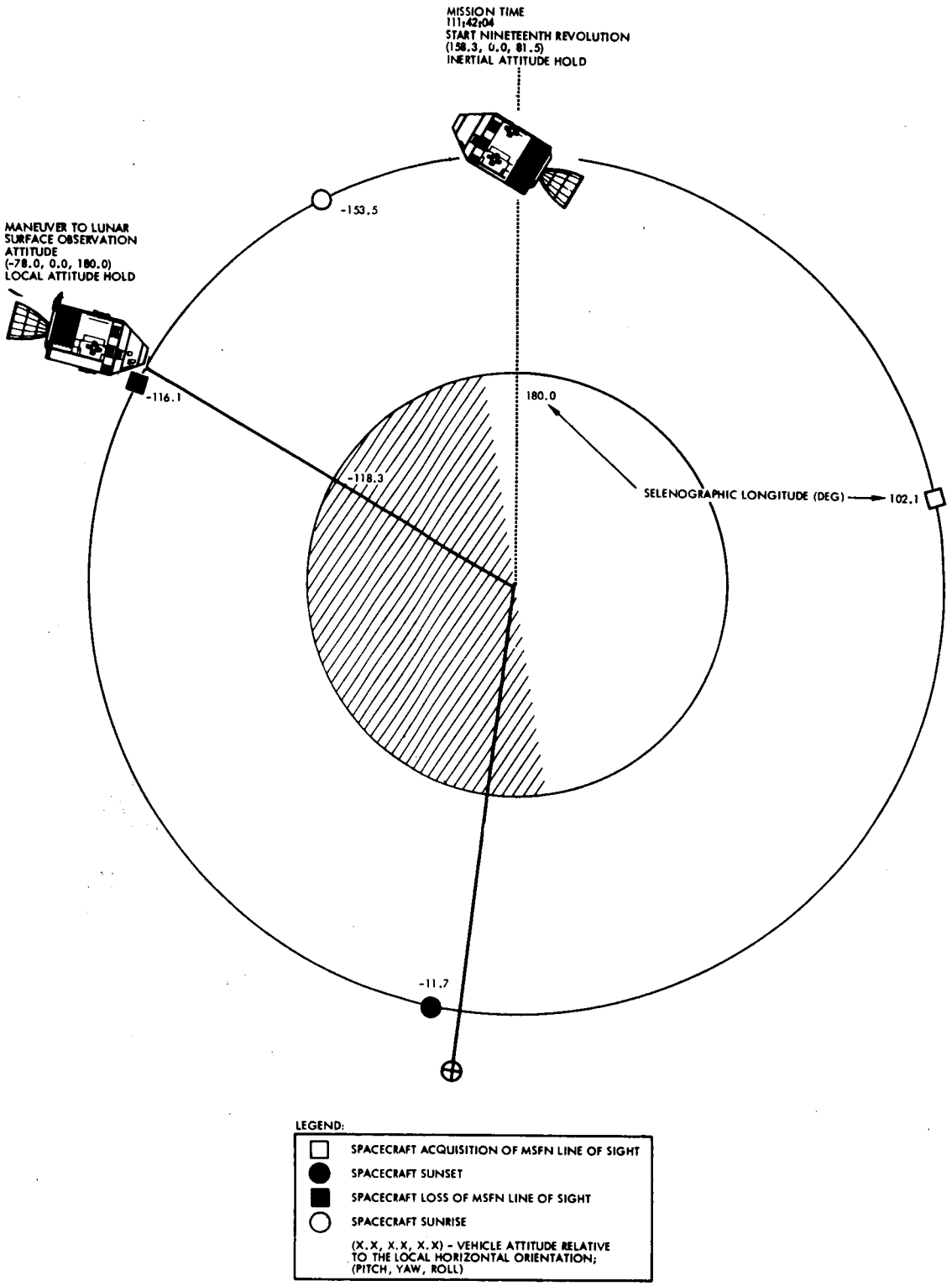


Figure 31. Nineteenth Revolution Major Events and Attitudes

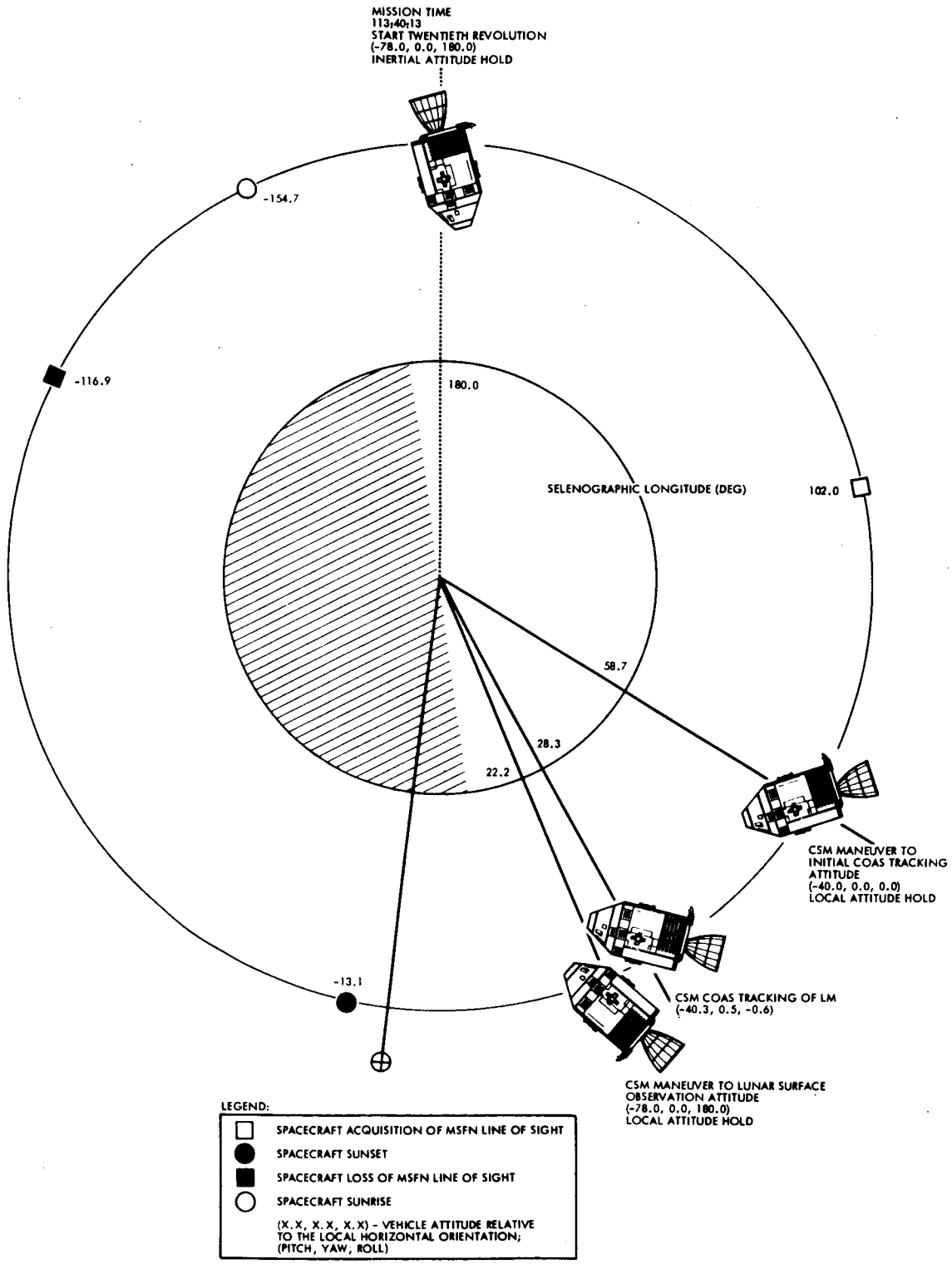


Figure 32. Twentieth Revolution Major Events and Attitudes

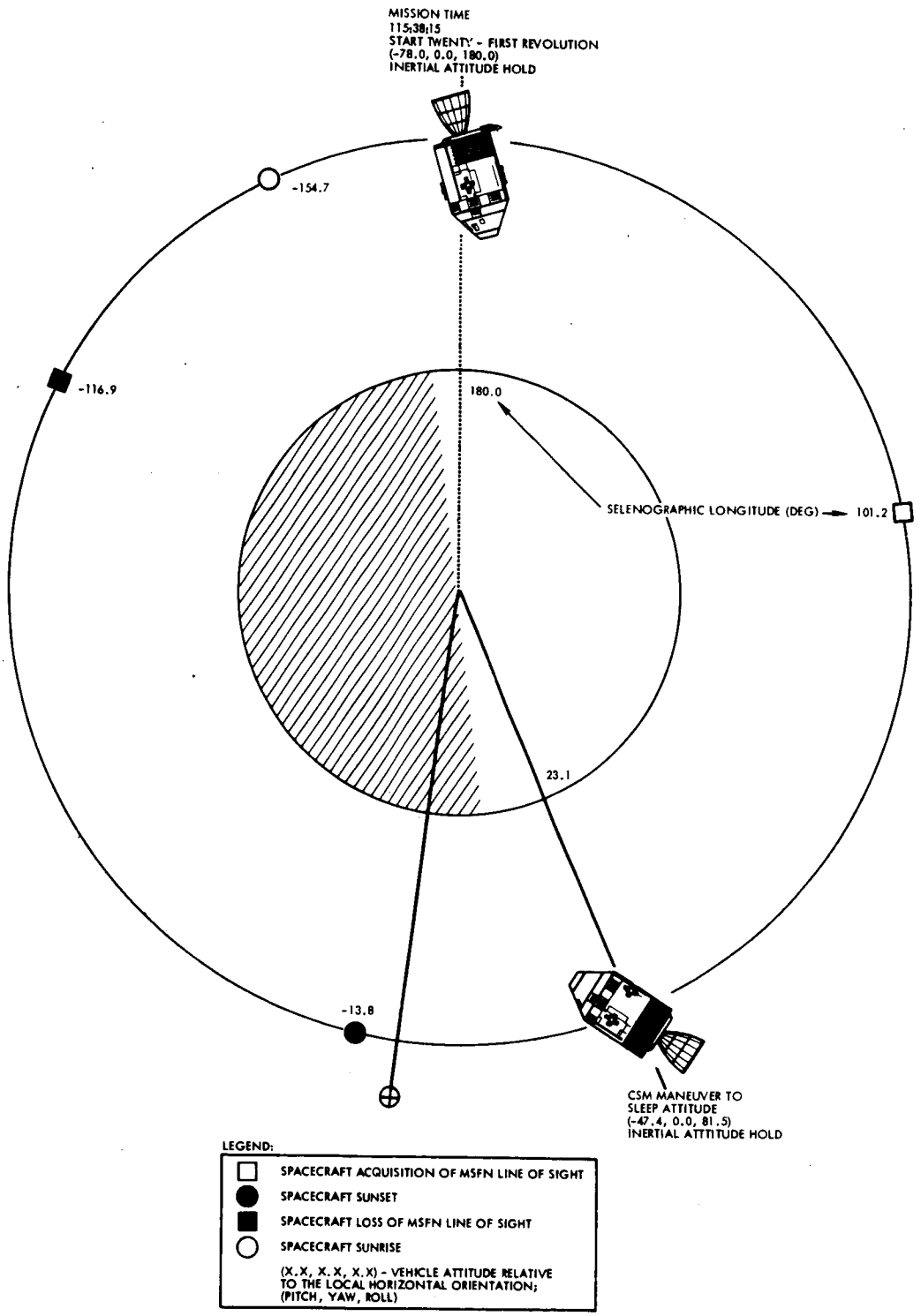


Figure 33. Twenty-first Revolution Major Events and Attitudes

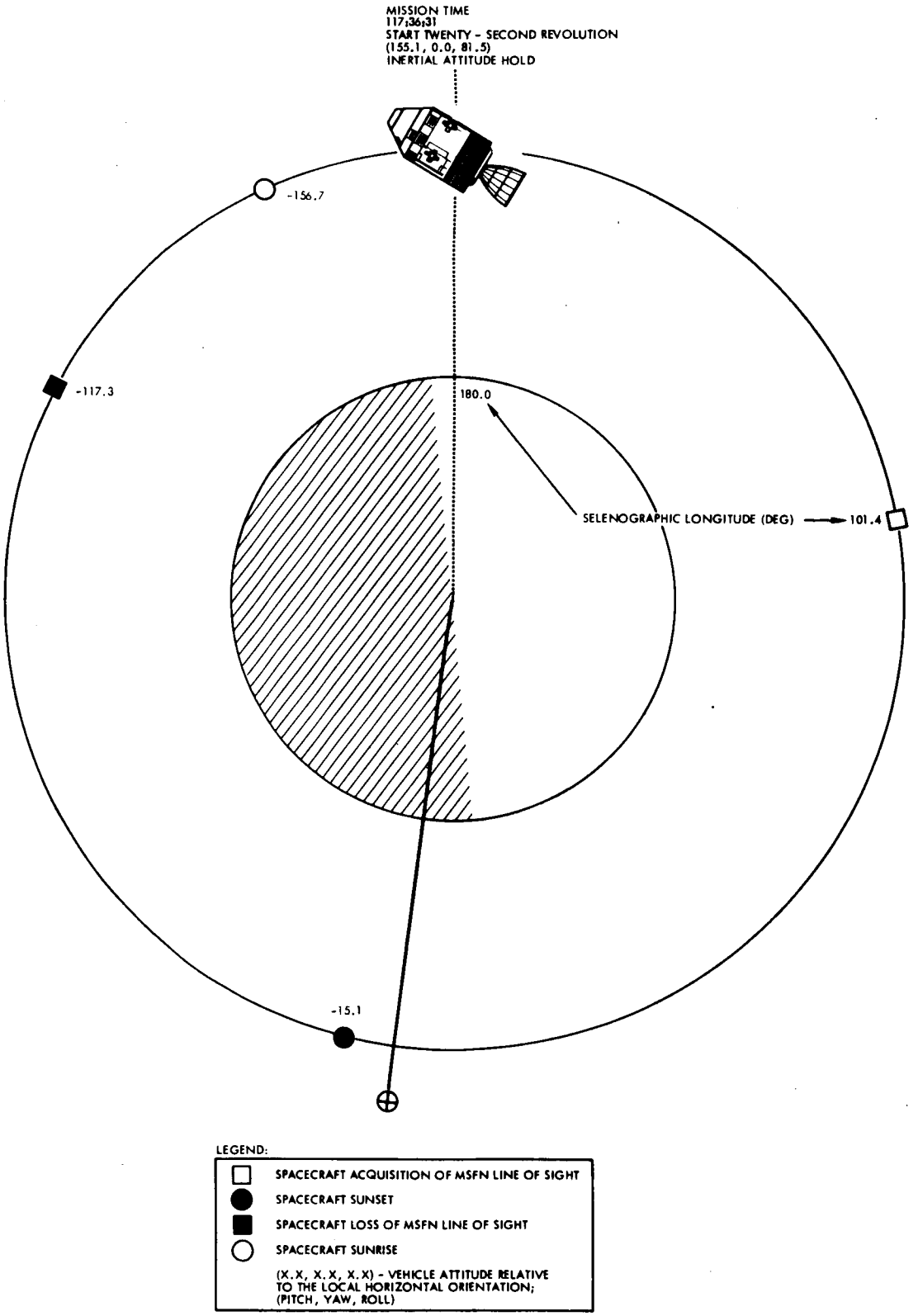


Figure 34. Twenty-second Revolution Major Events and Attitudes

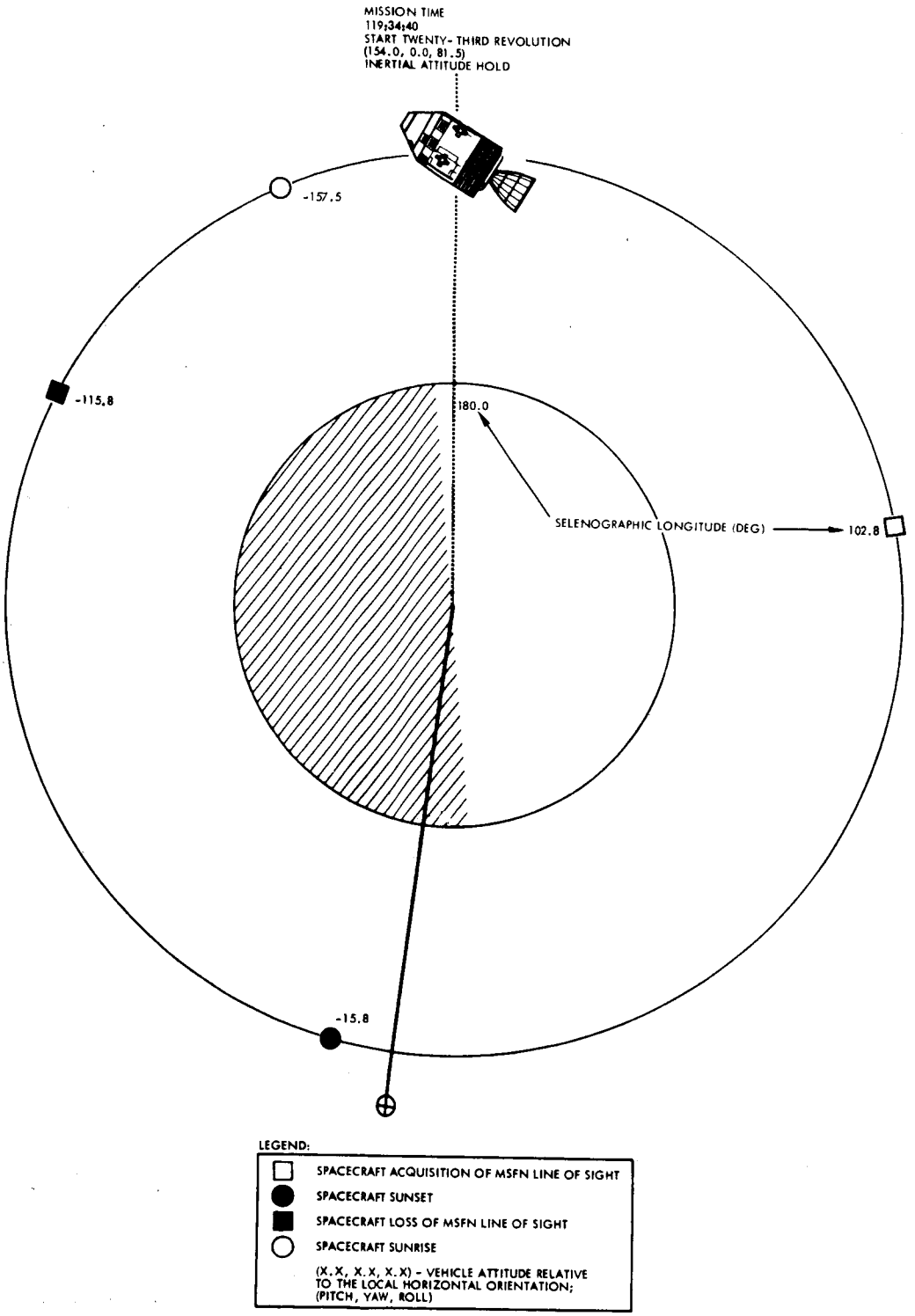


Figure 35. Twenty-third Revolution Major Events and Attitudes

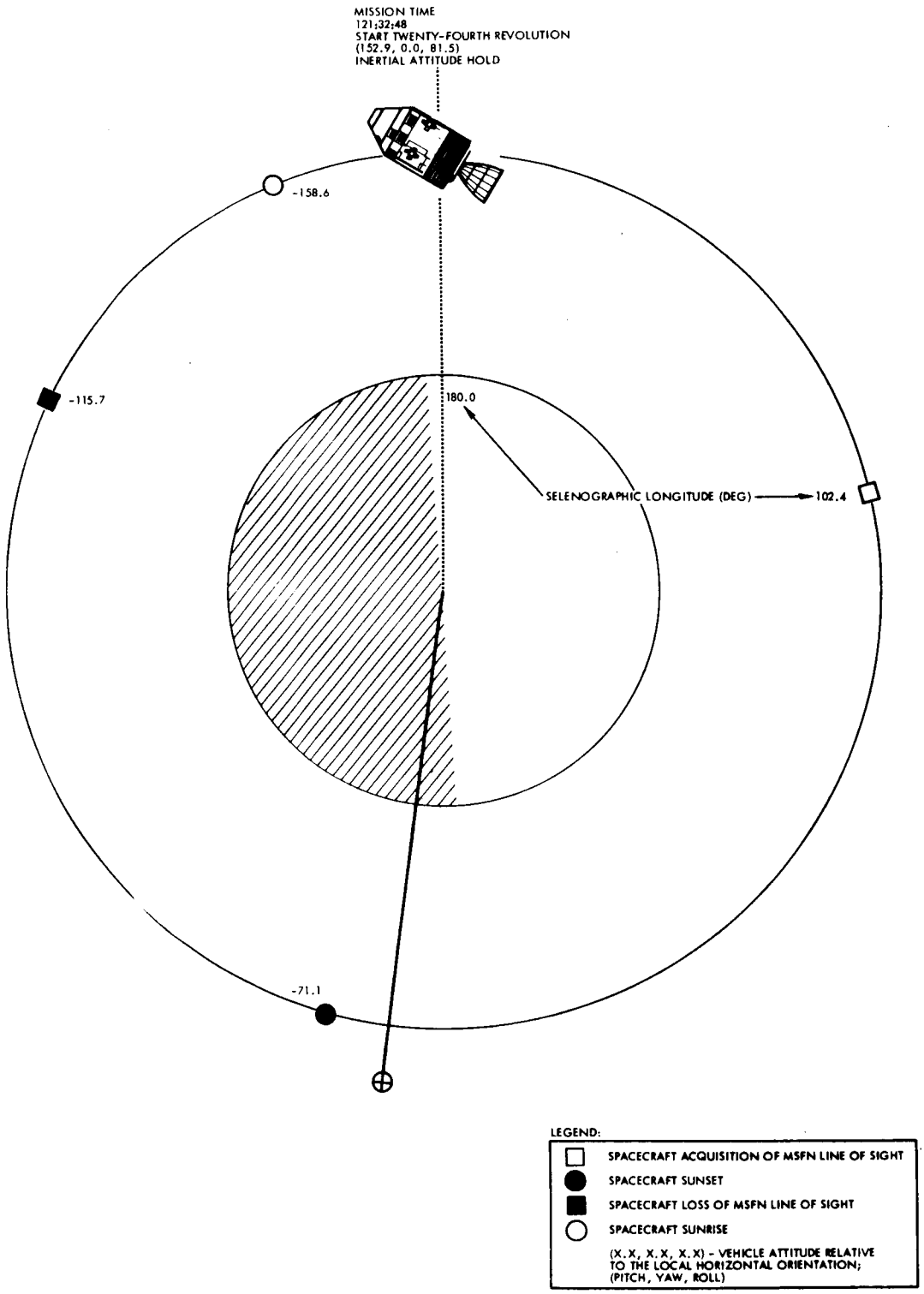


Figure 36. Twenty-fourth Revolution Major Events and Attitudes

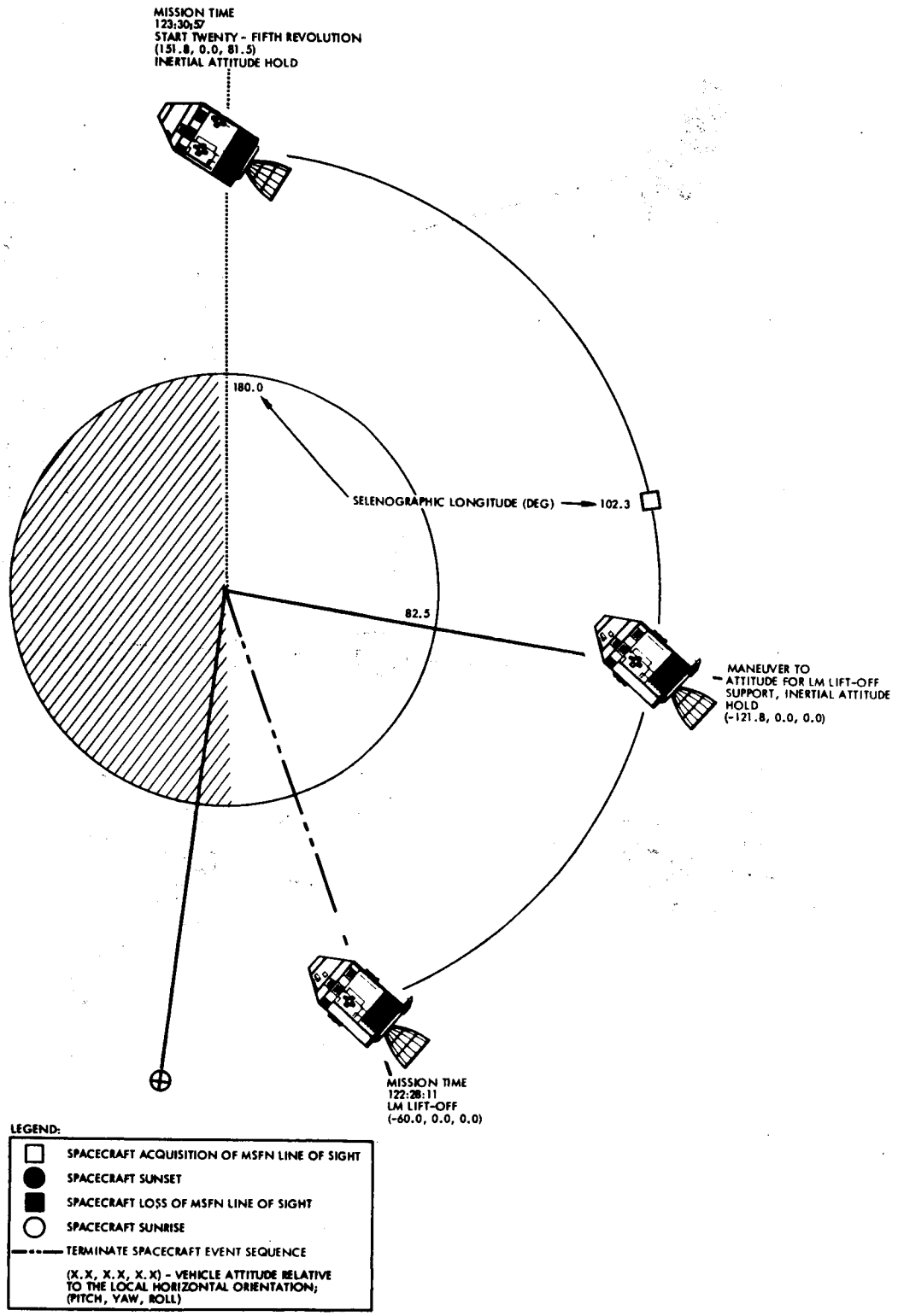


Figure 37. Twenty-fifth Revolution to LM Lift-off

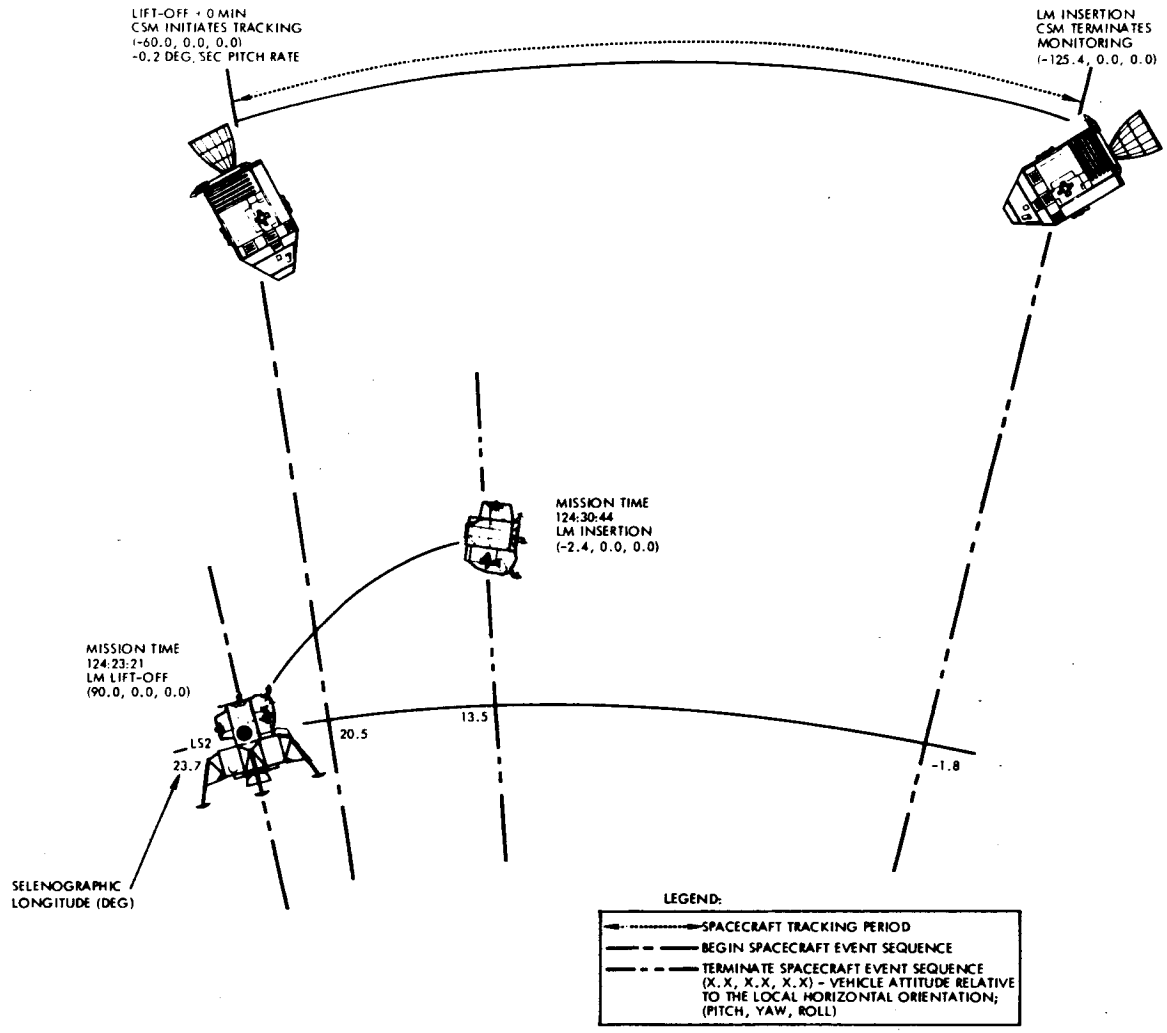


Figure 38. LM Lift-off to Insertion Burn Cutoff

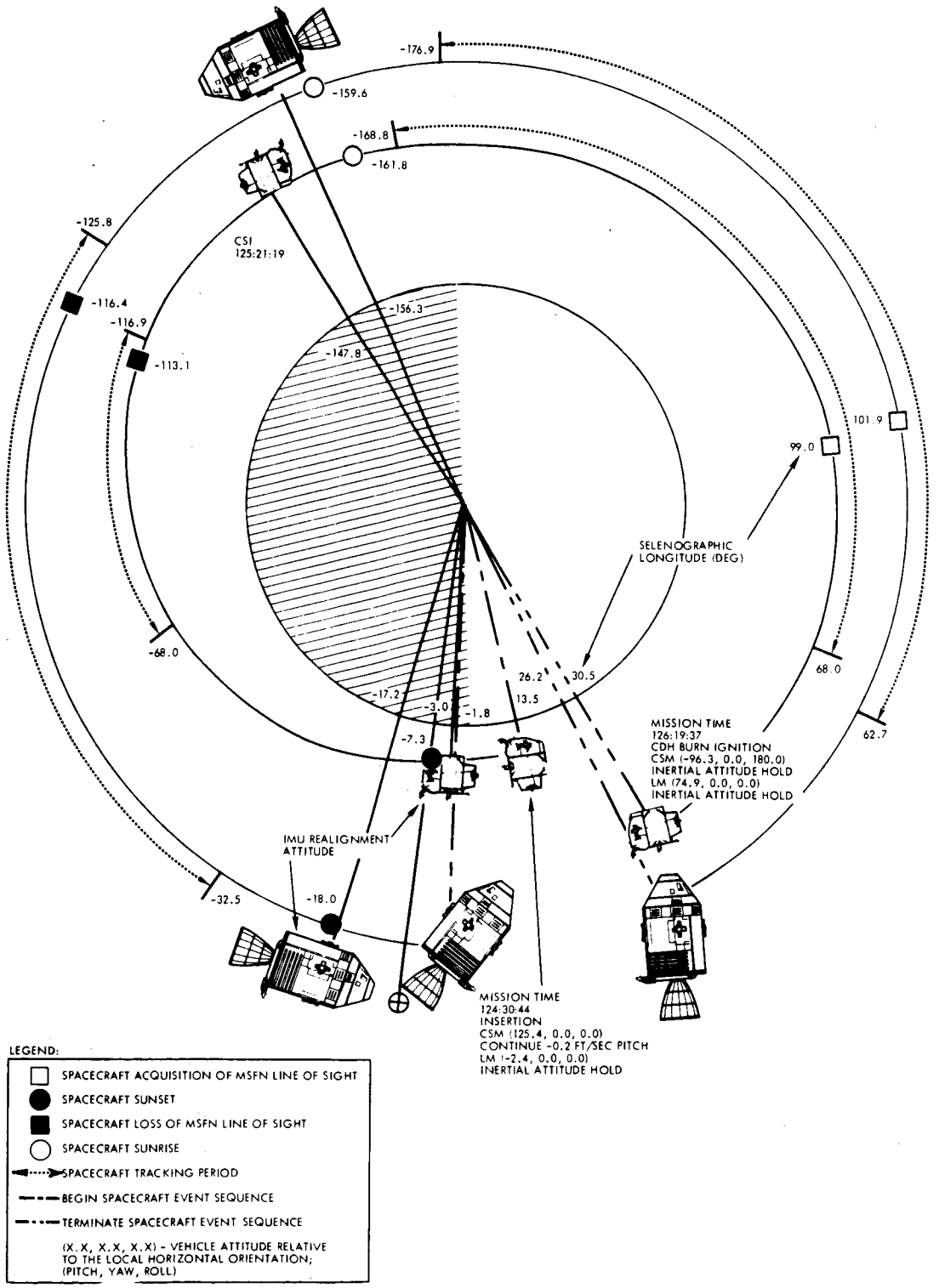


Figure 39. Insertion Burn Cutoff to CDH Burn Ignition

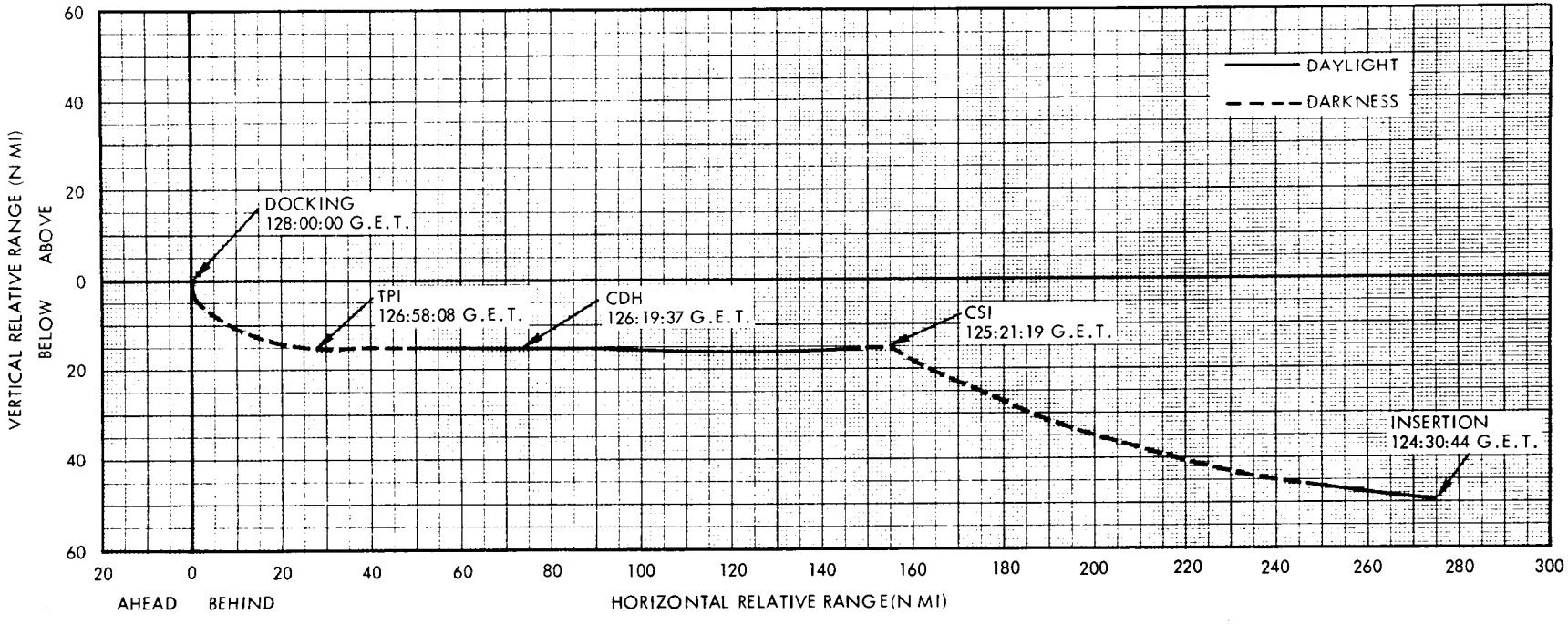


Figure 40. CSM-LM Relative Motion from Insertion to CSM/LM Docking (CSM Fixed)

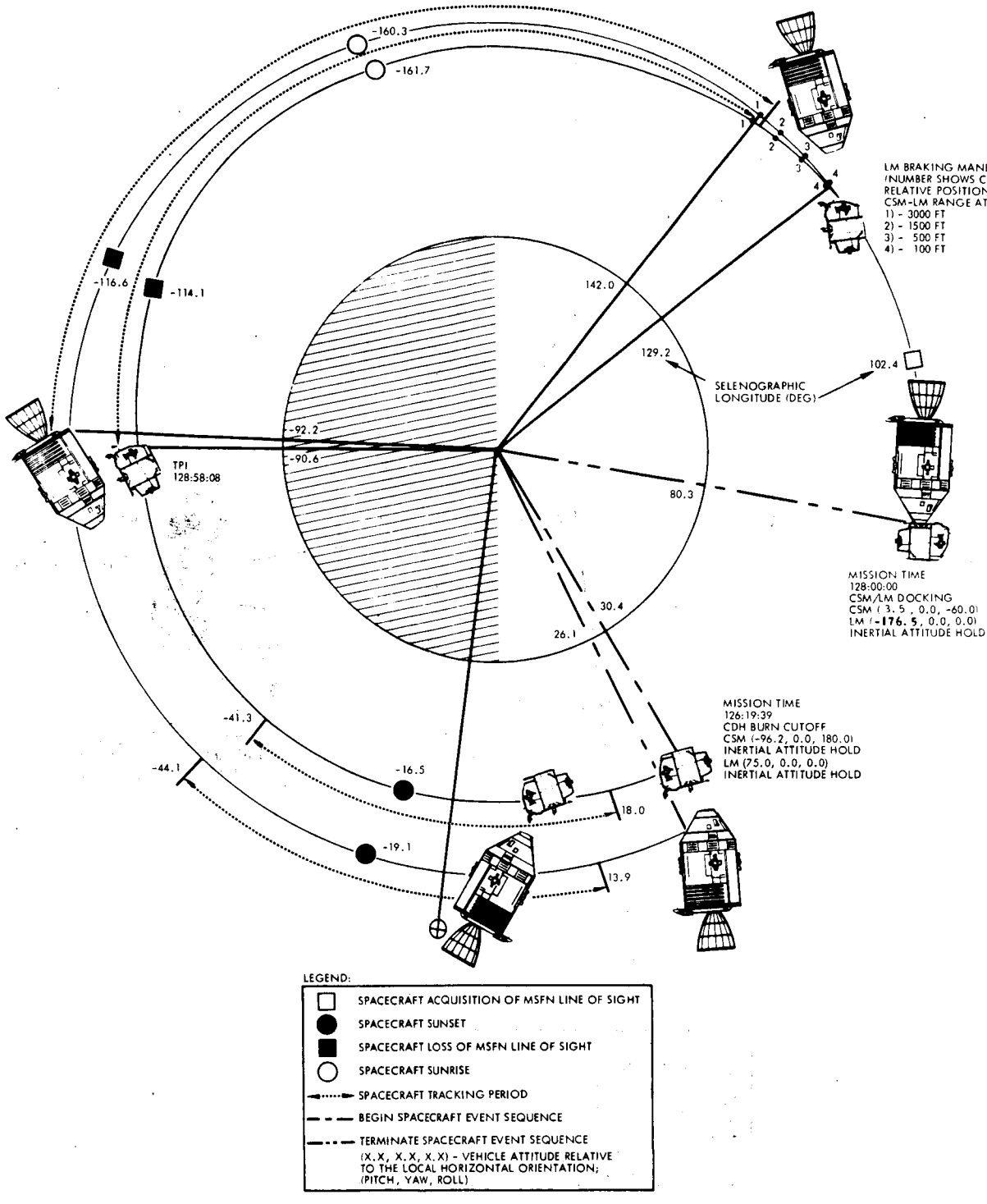


Figure 41. CDH Burn Cutoff to CSM/LM Docking

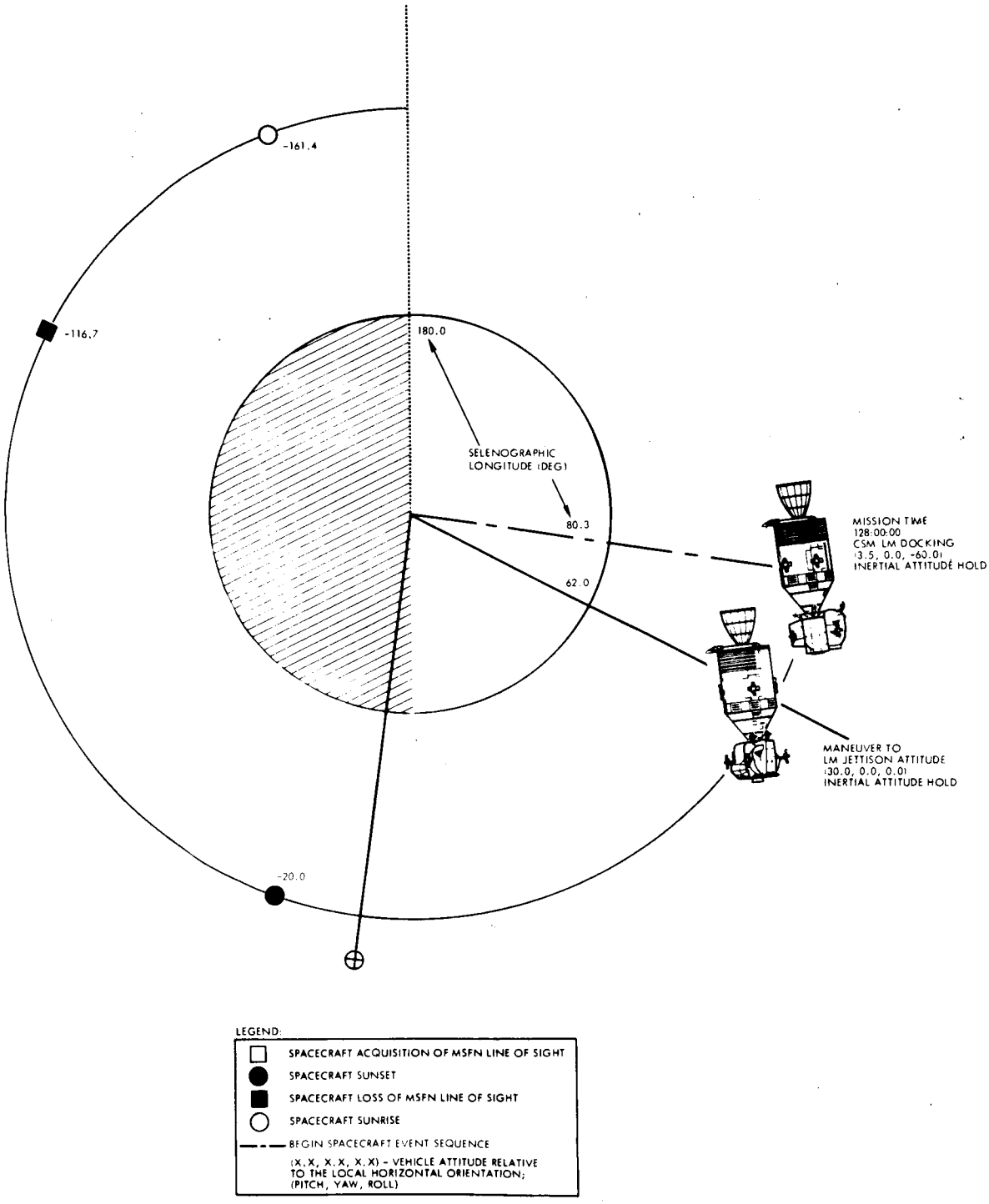


Figure 42. CSM/LM Docking to Completion of the Twenty-seventh Revolution

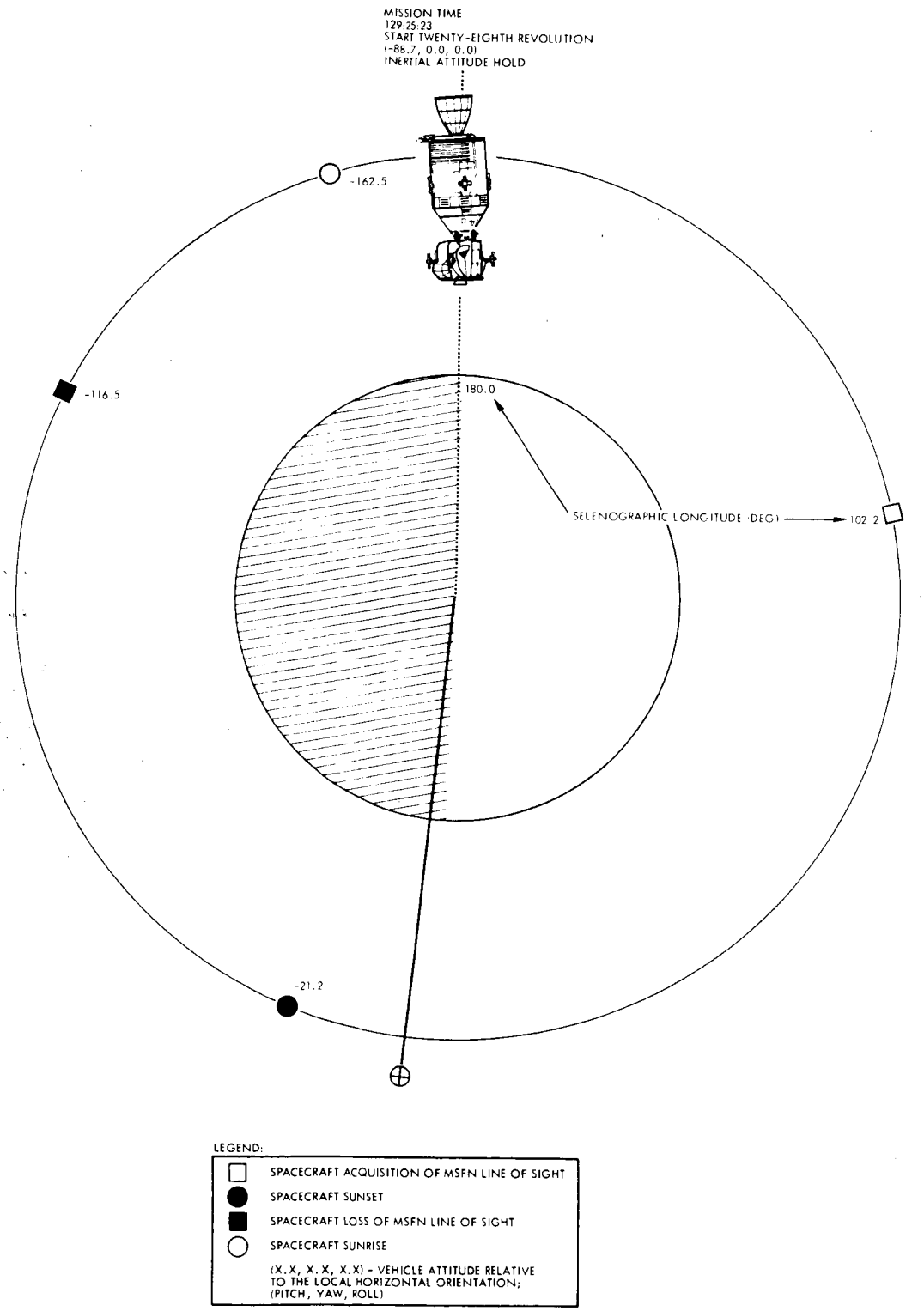


Figure 43. Twenty-eighth Revolution Major Events and Attitudes

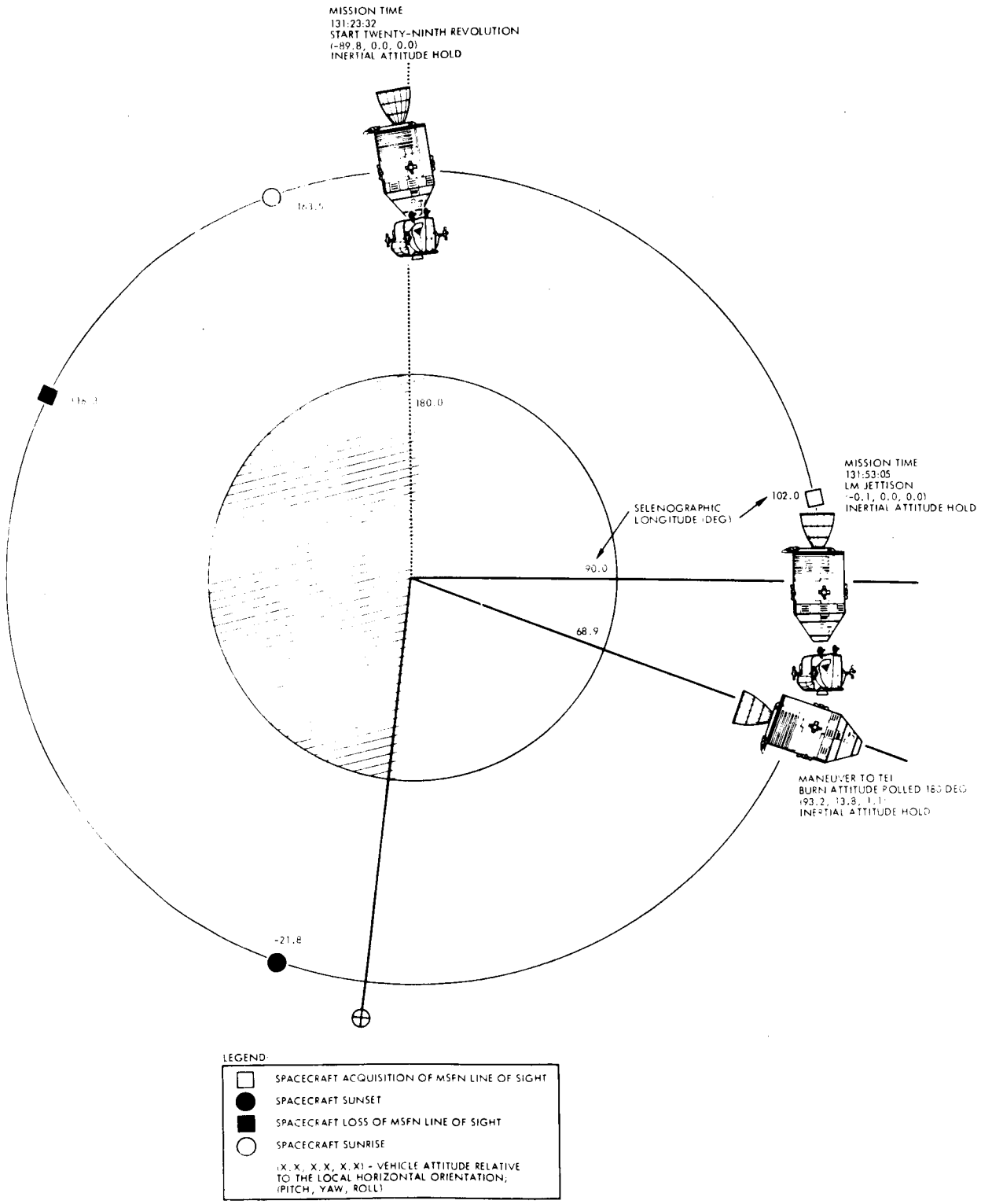


Figure 44. Twenty-ninth Revolution Major Events and Attitudes

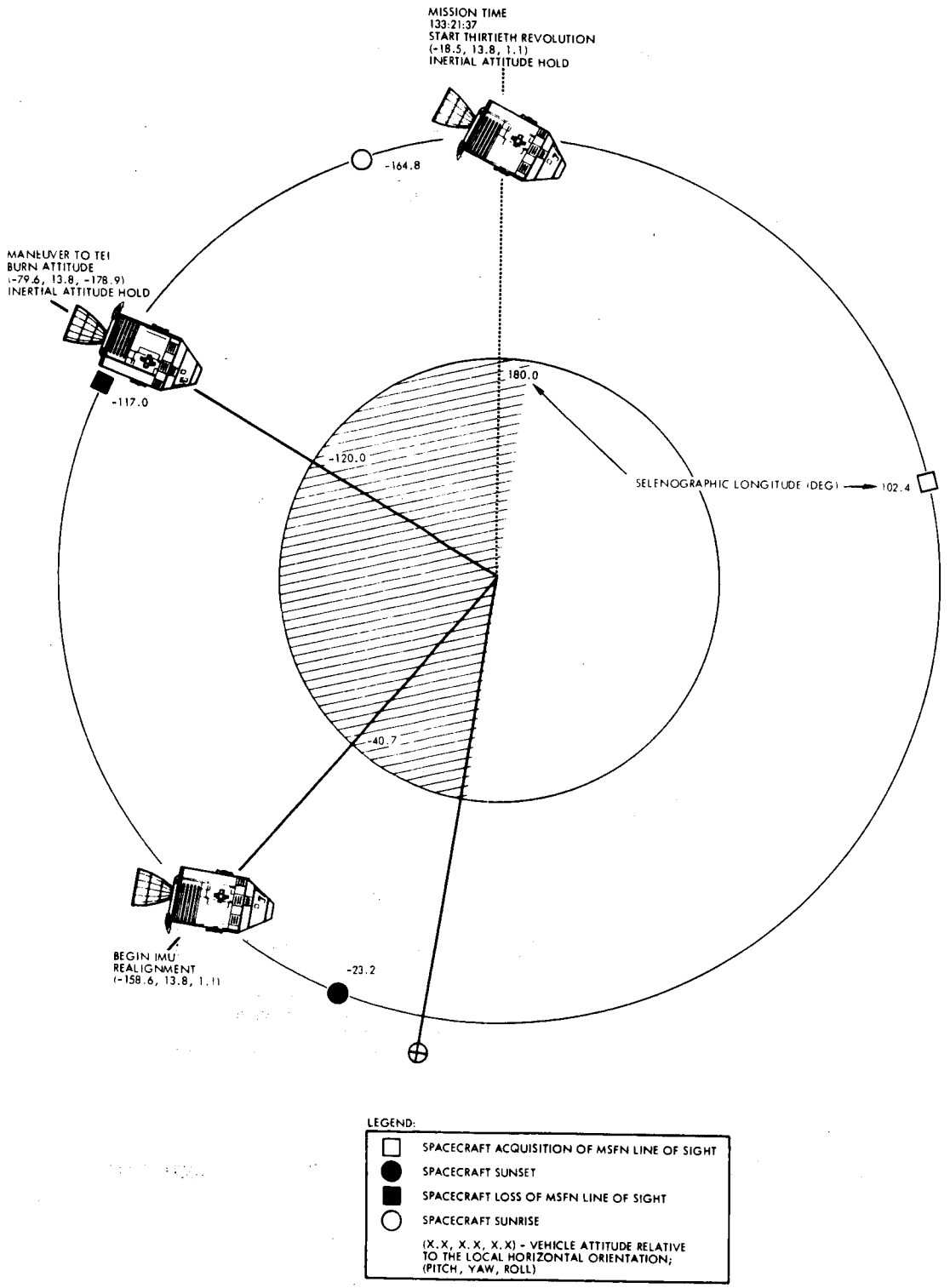


Figure 45. Thirtieth Revolution Major Events and Attitudes

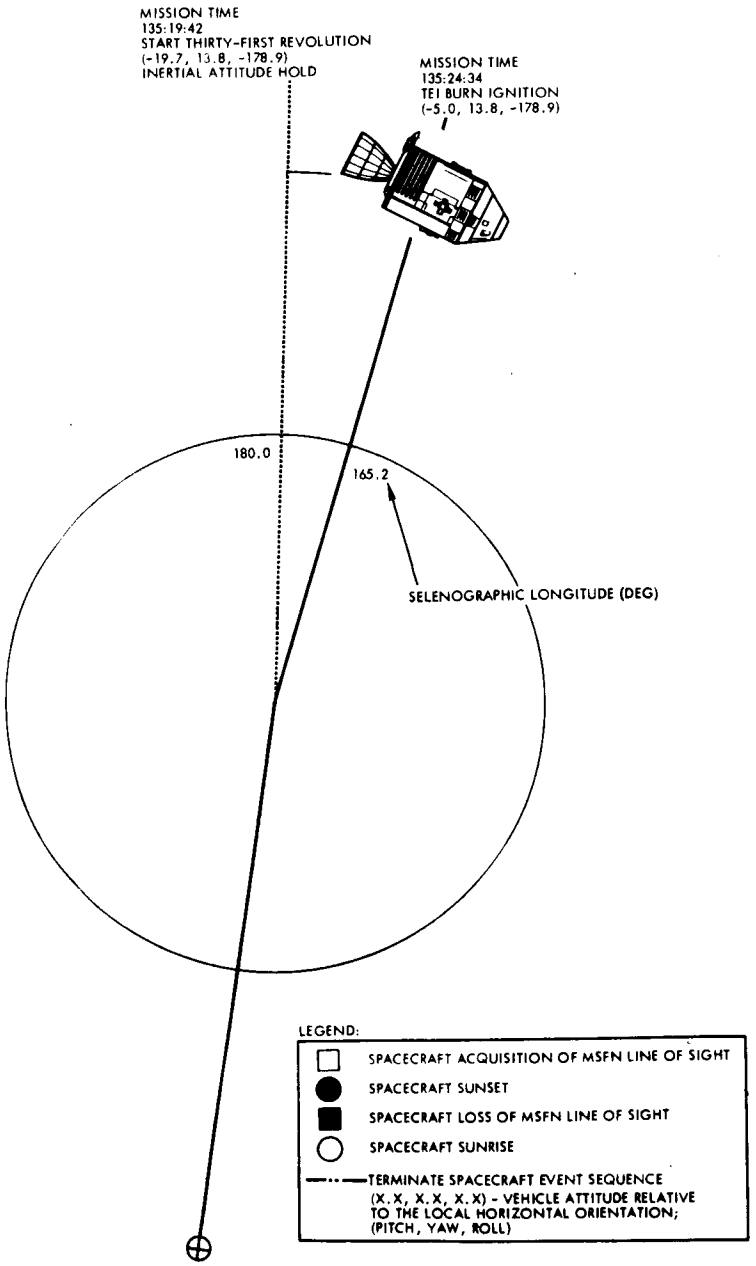


Figure 46. Thirty-first Revolution to TEI Burn Ignition

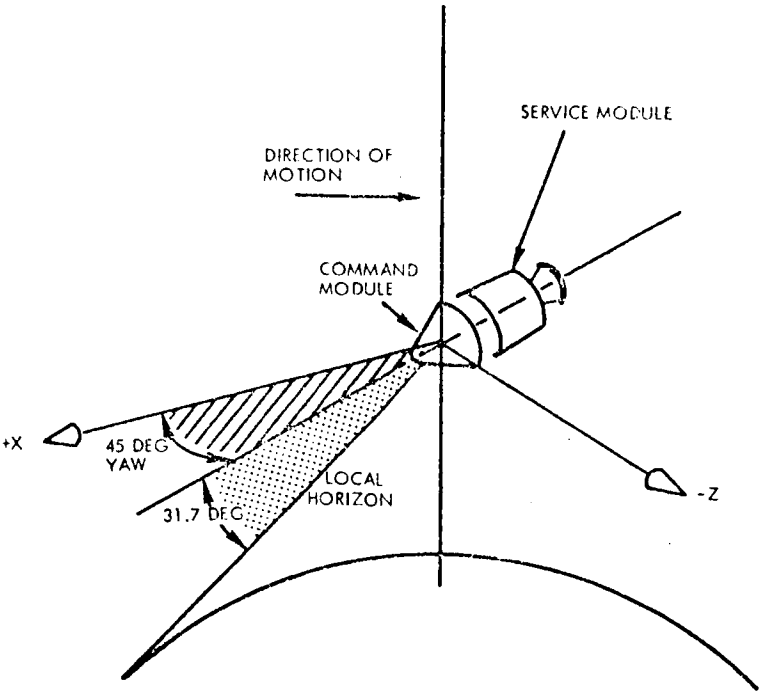


Figure 47. CM/SM Separation Attitude

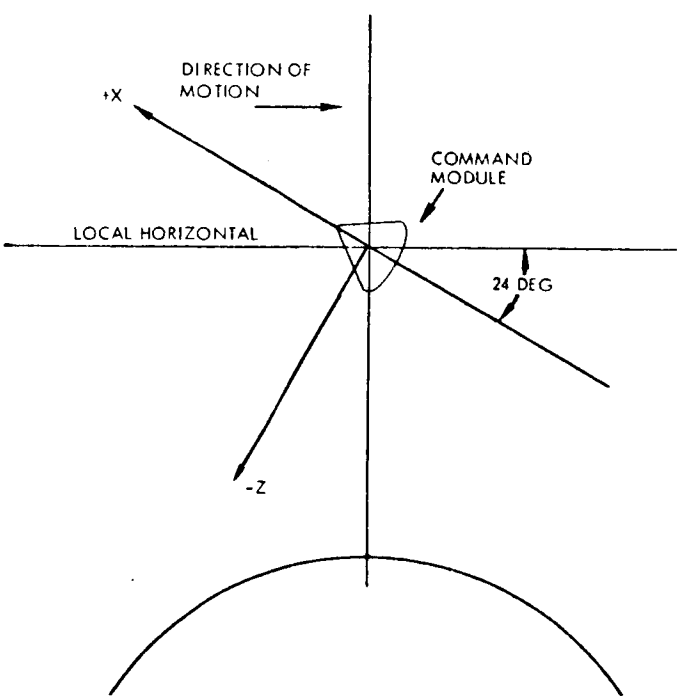


Figure 48. CM Entry Attitude

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